BETT TTEB

The Effects of Re-Insulation on Some Houses in Winnipeg

A RESEARCH REPORT

The Effects of Re-Insulation on Some Houses in Winnipeg

A RESEARCH REPORT

A Before-and-After Field Study of Houses in Winnipeg that have been Retrofitted by Addition of Loose-Fill Insulation to Ceilings or Walls

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ABSTRACT

Energy-related variables were monitored in six detached houses in Winnipeg, Manitoba before and after the houses were retrofitted by re-insulating the exterior walls and ceiling, or walls only, with blown loose-fill glass-fibre or cellulose insulation. The variables included interior relative humidities, interior air and building-envelope temperatures, decay heat loss, location of the neutral pressure plane, airtightness, steady-state furnace combustion efficiency, furnace on/off cycling time, and electricity and natural gas consumption. Thermographic scans of the building envelope from the interior and an energy audit of the building and occupants provided additional information.

Despite the diversity of house types represented in the study sample the monitoring confirmed expectations about, and provided quantitative information on, the major effects of the re-insulation: increases in airtightness, interior relative humidity, and building envelope temperatures, and reductions in air leakage, heat loss, and fuel consumption.

RÉSUMÉ

Certaines variables associées à l'énergie ont été mesurées dans le cadre d'une étude de six maisons unifamiliales à Winnipeg (Manitoba) avant et après l'exécution de travaux de réfection de l'isolation thermique des murs extérieurs et du plafond, ou uniquement des murs, grâce à un complément de matériau isolant de fibre en verre en vrac soufflée, ou à base de cellulose. Les variables retenues comprenaient les taux d'humidité relative à l'intérieur, les températures de l'air à l'intérieur et de l'enveloppe de l'immeuble, la réduction des pertes de chaleur, l'emplacement du plan de pression neutre, l'étanchéité, l'efficacité de la combustion de la chaudière en régime permanent, la durée du cycle marche-arrêt de la chaudière et la consommation d'électricité et de gaz naturel. Les analyses par balayage thermographique de l'enveloppe de l'immeuble de l'intérieur et une vérification du bilan énergétique de cet immeuble et des occupants ont permis d'obtenir des données supplémentaires.

Malgré la diversité des catégories de maisons représentées dans l'échantillonage, ce contrôle qui a confirmé les prévisions, a permis de fournir des données quantitatives sur les principaux effets de la réfection de l'isolation thermique, soit l'accroissements du taux d'étanchéité, de l'humidité relative à l'intérieur, de la température de l'enveloppe de l'immeuble et la réduction des fuites d'air des pertes de chaleur et de la consommation de combustible.

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When retrofit work is conducted on a house it may indirectly affect several aspects of the house performance. In some instances this may be advantageous, but in others it may be harmful. Interactional effects may therefore be an important part of retrofit design, but they have not been investigated to any significant degree to date.

Two parallel studies have been conducted to quantify the secondary effects of wall re-insulation: one in Winnipeg and one in Ottawa, to give some coverage of climatic variations. The main objectives were to investigate the effects of wall re-insulation on house infiltration performance, furnace performance and humidity levels. Significant changes were observed in each of the studies, but the sample sizes were not large enough and the experimental work was not extensive enough to allow precise quantification of the effects - for general application.

The significance of these two studies is that they confirm the existence of these secondary effects. In general, the secondary effects of wall re-insulation, of the type covered in the studies, was not large. However, it is reasonable to assume that the magnitude of the secondary effects will increase with the extent of the retrofit work. Thus re-insulation with rigid insulation sheathing, for example, might produce greater secondary effects and would possibly merit investigation.

This report deals with the study on houses in Winnipeg, The parallel study is covered in another report in this same series, entitled "The Effect of Re-Insulation on 8 Houses in Ottawa."

This report is issued as part of the activities of the Buildings Energy Technology Transfer Program - a program administered by the federal department of Energy, Mines and Resources. The objective of this program is to develop competent energy conservation technologies for buildings of all types, and to deliver these technologies to prospective users.

The report falls in the category of Low-Rise Residential buildings - a category that is managed by Saskatchewan Research Council under contract to EMR.

The report does not necessarily reflect the views or policies of either Energy, Mines and Resources or Saskatchewan Research Council. However, the fact that it has been issued is an indication that each of these agencies is satisfied that it comes up to the standards of the BETT program and advances the state of the art.

D. Eyre
Saskatchewan Research Council

April, 1983

Ce rapport fait état des résultats d'une étude sur place de six maisons à Winnipeg (Manitoba) effectuée avant et après l'exécution de travaux de réfection de l'isolation thermique des murs extérieurs et de l'entretoit, ou uniquement des murs, grâce à un complément d'isolant en vrac soufflé. Parmi les variables mesurées tant avant qu'après les travaux de réfection de l'isolation, il y a lieu de citer l'efficacité de la combustion en régime permanent, la durée du cycle marche-arrêt de la chaudière fonctionnant selon le principe de l'air pulsé, les températures à l'intérieur des murs et des plafonds au niveau de l'enveloppe de l'immeuble, les températures de l'air à l'intérieur et les taux d'humidité relative, l'emplacement du plan de pression neutre, la réduction des pertes de chaleurs et le taux d'étanchéité (à l'aide d'une méthode permettant de déceler les courants d'air). D'autres données ont été obtenues à l'aide d'analyses par balayage thermographique de l'intérieur de l'enveloppe de l'immeuble, d'analyses du bilan énergétique de l'immeuble et des occupants, et de l'obtention de données sur la consommation d'électricité et de gaz naturel.

1.1 Principaux résultats

Les résultats quantitatifs et qualitatifs ont permis de vérifier l'incidence prévue des travaux de réfection thermique à l'aide de la méthode de l'isolant soufflé. Les analyses thermographiques n'ont pas décelé de carances dans le mode d'isolation, que l'on aurait pu imputer aux techniques d'installation. Par contre, on a décelé certains vices cachés imputables à des modifications précédentes ou à la conception originale des maisons.

Le taux d'etanchéité a été accru de façon marquée lorsque les cavités dans les murs ont été comblées à l'aide d'isolant en vrac. On a enregistré une diminution des fuites de l'ordre de 5 à 33% dans les six maisons étudiées. Les analyses par balayage à infrarouge ont permis de constater que la sablière, et notamment la sole étaient les principales zones exposées aux fuites d'air, en plus des fenêtres, des portes et des prises électriques; mais ces analyses ont également permis de démontrer que la pose de matériau isolant a entraîné une diminution des fuites à ces endroits.

Le plan de pression neutre, qui dans la plupart des cas, était situé à proximité du sommet de l'enveloppe de l'immeuble (plafond), s'est légèrement déplacé vers le haut par suite de l'imposition de l'évacuation par tirage (fonctionnement de la chaudière). La réfection thermique des murs et des plafonds a eu peu d'effet sur son emplacement, toutefois.

Les températures de la surface intérieure des sections de l'enveloppe extérieure, dont l'isolation a été refaite de même que les températures de l'air à l'intérieur se sont accrues dans la plupart des cas, mais une variation marquée d'un mur à l'autre a été enregistrée. Le taux de régression de la température de l'air à l'intérieur, lorsque de la chaudière fonctionnait pas, a diminué de façon significative. L'évolution des taux d'humidité imputable de réfection était modeste, mais dans cinq des six maisons étudiées, une hausse de ces taux a été enregistrée.

Aucun indice n'a permis de conclure à une modification du rendement de la chaudière par suite de la réfection de l'isolation thermique; en outre, on n'a pas constaté de tendances distinctes relativement à l'efficacité de la combustion en régime permanent, et le temps de combustion par cycle n'a décru que de façon marginale. En se fondant sur un contrôle du cyc[illegible] de fonctionnement de la chaudière, on a pu projeter, dans le cas des six maisons étudiées, une baisse de la consommation de combustible de l'ordre de 9 à 41%.

1.2 Conclusions

Il sera possible d'utiliser les données compilées aux fins d'une analyse plus détaillée des changements survenus dans chaque maison en fonction des travaux de réfection qui y ont été exécutés, et de comparer et d'évaluer les différentes techniques empiriques et prévisionnelles. Les variations constatées dans le cas de chaque catégorie de maison et l'étendue des travaux de réfection ne permettront pas toutefois de généraliser de façon quantitative les résultats résumés ci-dessus à l'ensemble du parc résidentiel. La valeur du projet semble

surtout reposer sur l'expérience acquise au cours de son exécution. En ce qui a trait aux résultats du programme de contrôle, les différentes conclusions qui ont été tirées peuvent convenir à des travaux connexes ou complémentaires.

1.2.1 La portée d'une analyse du bilan énergétique résidentiel et, dès lors, la somme des efforts requis aux fins de la compilation de ses résultats, seront fonction de l'utilisation que l'on compte en faire. Dans bon nombre de cas, et notamment si l'objectif établi est d'obtenir des données auc fins d'une analyse détaillée et de l'établissement de modèles mathématiques, la méthode d'analyse pourra être simplifiée dans la mesure où un tableau général de valeur R.S.I. concernant une grande diversité d'éléments complexes de construction pourra être utilisé par des vérificateurs et analystes.

1.2.2 La recherche énergétique entreprise dans un habitat occupé présente des problèmes uniques. Des rapports peuvent facilement s'établir entre un chercheur et un résident notamment dans le cadre d'un projet pertinent comme les économies d'énergie dans l'habitat; par contre, l'incidence des activités de l'occupant, et les contraintes que pose le maintien d'un mode de vie quasi normal dans la résidence, sont des éléments majeurs qui peuvent influer sur la planification et l'exécution des essais. Par exemple, l'environnement intérieur au cours de la saison froide est en grande partie contrôlée à partir du thermostat. Les ajustements exécutés par le propriétaire peuvent influer de façon systematique sur les variables contrôlées, qui sont difficiles à dégager dans l'anlyse. Il y aurait lieu d'envisager, dans le cadre d'études ultérieures sur l'évaluation de travaux de réfection l'incidence du réglage du thermostat, ou du moins, de retenir cet élément comme paramètre.

Les séries de relevés ponctuels effectuées par les propriétaires et l'équipe chargée du projet dans le cadre de la présente étude ne permettaient pas d'évaluer de façon précise les variables dynamiques qui suivent: soit la température de l'air et l'humidité relative à

l'intérieur, facteurs assujettis aux fluctuations temporelles et à court terme imputables aux activités humaines, et les températures de la surface de l'enveloppe de l'immeuble, qui traduisent l'évolution temporelle et spatiale des condiutions qui prévalent à l'intérieur et à l'extérieur. Un contrôle suivi pourrait dès lors constituer un pré-requis nécessaire aux fins d'une description valable de l'environnement intérieur.

L'essai relatif à la réduction des pertes calorifiques doit être repensé pour éviter, dans la mesure du possible de perturber le mode de vie des occupants d'une résidence. Étant donné que ce genre d'essai peut surtout servir à effectuer une évaluation quantitative et objective de la capacité de rétention calorifique de l'immeuble, l'établissement d'une méthode normalisée et la définition d'indicateurs pertinents sont clairement justifiés. Un tel essai pourrait ainsi servir de complément à celui, déjà bien établi, qui sert aux fins de l'essai d'étanchéité, sauf que l'on a eu recours à un régulateur de pression externe. L'utilisation de régulateurs multiples, comme proposée dans la version préliminaire, aurait rendu l'exécution de l'essai plus malaisée. Le facteur rapidité est sans doute plus important que la précision dans le cas d'un essai de cette nature, dont les résultats s'établissent sous forme de moyennes applicables à l'ensemble de la résidence.

1.2.4 L'analyse par balayage à infrarouge de l'utilisation de poires à fumée en vue de localiser le plan de pression neutre dans les maisons sont des techniques qualitatives qui peuvent profiter tant à l'analyste qui étudie le phénomène d'infiltration et de fuite, et la réaction de ce phénomène aux mesures de réfection de l'isolation thermique, qu'aux propriétaires, dans le cadre de programmes de formation en matière d'énergie.

1.2.5 Le contrôle direct du rendement de la chaudière et de son comportement cyclique au cours de périodes brèves sert davantage aux analystes qui évaluent de façon empirique les mesures de réfection thermique que la tenue de registres sur la consommation de combustible à

long terme. Danbs ce dernier cas, il serait utile d'établir un relevé chronologique concernant les quelques années qui précèdent et qui suivent l'adoption d'une mesure particulière visant la consommation d'énergie, pour pouvoir ainsi déterminer l'influence de certains éléments, comme part exemple, les phénomènes climatiques et inhabituels. Dans le premier cas, une méthode fondée sur des éléments et inhabituels. Dans le premier cas, une méthode fondée sur des éléments physiques, et axée sur l'environnement extérieur à court terme (par exemple, la température, le vent, l'effet du soleil) comme variable indépendante, permettrait une évaluation davantage immédiate. Pour le moment, cette technique se doit d'être développé.

1.3 Recommandations

La somme d'efforts et les frais que représentent l'étude et le contrôle d'un nombre élevé de résidences de faible hauteur peuvent ne pas se justifier lorsque l'on s'en remet à la valeur apparente des données qui sont obtenues, sauf si les recherches se limitent à la mesure d'un nombre minimal de variables précises. Bien que les avantages qu'offrent généralement les travaux de réfection thermique aioent été clairement confirmés par suiote des observations faites dans chacune des maisons décrites dans le présent rapport, la conclusions dominante qui s'en est dégagée est celle d'une absence d'uniformité, tant dans le cas de l'ensemble des maisons, que des murs ou sections de mur. En outre, chaque projet de réfection de l'isolation thermique était unique de soi. Par conséquent, des conclusions définitives ne peuvent être établies, et on peut également se demander si d'autres données auraient dû être compilées.

Par suite de ces constatations, il est recommandé une méthodologie à deux niveaux aux fins des études ultérieures des travaux de réfection de l'isolation thermique ou d'autres projets de réfection.

Pour comprendre l'incidence d'une modification physique majeure d'un immeuble, comme l'amélioration de l'isolation dans les murs, on propose un programme de contrôle intensif à

priori et à postériori applicable à un nombre restreint de maisons choisies avec soin. Il pourrait s'agir d'une version extrapolée de la présente étude, pour ensuite améliorer le champ d'investigation temporel et spatial de certaines variables. À cette fin, les appareils enregistreures à canaux multiples pourraient se révéler essentiels aux fins de la mesure des températures normales, de l'humidité et de la pression barométrique, et dans le cadre d'essais sur la réduction des pertes calorifiques et de l'étude du mouvement du plan de pression neutre.

Le choix des maisons à étudier peut se révéler problématique, l'objectif étant de caractériser l'incidence de travaux types sur le parc résidentiel canadien. Il serait sans doute approprié de choisir des maisons dont la conception, l'âge et la condition soient semblables. De cette façon, des résultats très précis susceptibles d'êtres obtenus pourraient ainsi être vérifiées, et les particularités de chaque maison, qui pourraient influer sur chaque résultat, pourraient être établies et dégagées. Si des problèmes qui découlent de mesures prises en matière de réfection de l'isolation thermique sont découverts, on pourra alors les étudier de façon plus précise en fonction d'une plus grande diversité de maisons.

Dans le cadre du deuxième niveau de recherchem proposé comme suivi à l'étude courante, il s'agit de contrôler les économies de combustibles réalisées par suite de travaux de modification aux fins des économies d'énergie, comme la réfection de l'isolation thermique, dans un grand nombre de maisons qui représentent la gamme complète du parc d'habitation existant. Étant donné le caractère continu des efforts déployés en vue de la réfection des habitations et l'évolution des habitudes des occupants, les relevés à long terme de consommation de gaz, d'électricité et de mazout peuvent ne pas indiquer de façon précise les baisses de consommation d'énergie que l'on peut attribuer à l'un de ces travaux de réfection. À titre de solution, on recommande le contrôle direct du fonctionnement de la chaudière pour de courtes périodes, avant et après l'exécution des travaux de réfection.

Un nombre considérable de maisons pourrait être étudiés simultanément et à faible coût si le propriétaire participait à la lecture des compteurs du genre de ceux utilisés dans la présente étude. Les avantages accrus que pourrait représenter un programme de relevés continus devraient être évalués en tenant compte des coûts supplémentaires associés. Une étude serait de toute façon limitée à la saison froide, et l'on devrait tenir compte au cours de l'analyse ultérieure, de l'incidence à court terme du rayonnement solaire, des vents, et du comportement des occupants.

This report describes a "before" and "after" field study of six houses in Winnipeg, Manitoba which were retrofitted by re-insulating both exterior walls and attics, or exterior walls only, using blown loose-fill insulation. Variables measured both before and after the re-insulation included steady-state combustion efficiency and on/off cycling time of the forced-air furnace, interior temperatures of the walls and ceiling at the building envelope, interior air temperatures and relative humidities, the neutral pressure plane location, decay heat loss, and airtightness (using a draft procedure). Additional information was obtained in the form of interior thermographic scans of the building envelope, energy audits of the building and occupants, and records of both electricity and natural gas consumption.

1.1 Principal Findings

The quantitative and qualitative results verify the expected effects of re-insulation by the blown-in method. Thermography exposed no areas of poor coverage which could be attributed to the installation technique. Instead, a number of hidden problems related to previous alterations or the original designs of the houses were discovered.

Airtightness was increased significantly when empty wall cavities were filled with loose insulation. Reductions in Equivalent Leakage Area of 5 to 33 percent were recorded in the six study houses. The infrared scans revealed that the top-plate and, especially, the sill-plate areas were major problem points for air leakage, along with the (expected) windows, doors, and electrical outlets, but they also showed that the placement of insulation was effective in reducing the leakage at those points.

The neutral pressure plane, which in most cases was located near the top (ceiling) of the building envelope, was observed to rise slightly with the imposition of an exhaust draught (furnace operation). The re-insulation of walls and ceiling had little effect on its position, however.

Temperatures on the inner surfaces of retrofitted portions of the exterior envelope, as well as adjacent interior air temperatures, were increased in most cases, but significant variation from wall to wall was recorded. The rate of decay of interior air temperature with the furnace not operating was reduced significantly. Changes in humidity levels wrought by the re-insulation were modest, but in five of the six houses increases were recorded.

Evidence of change in furnace efficiency with increased insulation was inconclusive with no distinct trend in steady-state combustion efficiency being observed and with burn time per cycle decreasing only marginally. On the basis of a monitoring of furnace cycling, reductions in fuel consumption of approximately 9 to 41 percent were projected for the six houses examined.

1.2 Conclusions

It will be possible to utilize the collected data in more detailed analysis of the response of each study house to its re-insulation retrofit, and to compare and evaluate the various predictive and empirical techniques. The variations in house type and degree of re-insulation encountered in the study, however, will preclude a quantitative generalization of the findings summarized above to the housing stock at large. The main value of the project lies in the experience gained during its execution. Regarding this outgrowth of the monitoring program, several conclusions have been drawn which are relevant to related or follow-up work.

1.2.1 The depth of a residential energy audit and, hence, the effort required for its compilation will depend upon its planned ultimate use.
Simplification of the audit procedure in many cases, especially if the objective is to obtain information for detailed analysis and mathematical modelling, could be effected if a comprehensive table of RSI values covering a wide variety of assemblies were sanctioned for use by auditors and analysts.

1.2.2 Energy research in occupied housing presents unique problems. A researcher-resident rapport built from a base in such a relevant topic as home-energy conservation can be established with ease, but, in spite of this, the effect of occupant activities, together with the constraints forced by the necessary maintaining of near-normal lifestyles in the house, remains a major consideration in the planning and completing of experiments. For example, the interior environment during the heating season is largely controlled from the thermostat. Adjustments by the homeowner may induce systematic responses in monitored variables which are difficult to isolate in analysis. An appropriate component of future retrofit-evaluation studies therefore may be the assumption of control over the thermostat setting, or, at the least, its inclusion as a parameter to be observed.

The sets of spot measurements made by the homeowners and the project team during this study were insufficient to allow accurate characterization of the following dynamic variables of interest: interior air temperature and interior relative humidity, both due to the short-term temporal fluctuations caused by human activities, and, building envelope surface temperatures, which reflect the temporally and spatially changing interior and exterior conditions. Continuous monitoring may therefore be a necessary precondition for a useful description of the interior environment.

The decay heat loss test should be refined to a form which minimizes disturbance to lifestyle if it is to be run in an occupied home. As its major use could be for the purpose of yielding an unbiased quantitative assessment of the heat-retaining capability of a building, the development of a standard procedure and the definition of relevant indicators are clearly warranted. Such a test would complement that already well developed for airtightness.

1.2.3 A draft form of a standard procedure for the airtightness test was followed in this study, except that a single outdoor pressure tap was employed. Use of multiple taps as suggested in the draft would

have made the execution of the test more cumbersome. Speed may be a more important consideration than accuracy in a test of this nature which yields performance data in the form of house-wide averages.

1.2.4 Infrared scanning and the use of smoke pencils to locate the neutral pressure plane in the test houses are qualitative techniques which may be of benefit both to the analyst studying the infiltration-exfiltration phenomenon and its response to retrofit measures, and to the homeowner as a part of energy-education programs.

1.2.5 Direct monitoring of furnace efficiency and cycling behaviour over short periods is potentially of more value to analysts empirically evaluating retrofit measures than is the keeping of long-term fuel consumption records. A chronological sequence of the latter data, representing several years before and after the implementation of a particular energy-consumption measure, may be required to overcome the biasing effect of, for example, unusual climatic occurrences. A physically based approach relying mainly on the former sources of information, with attention to the short-term exterior environment (e.g., temperature, wind, solar effect) as the independent variable, could allow a more immediate evaluation. Some development of this technique is, as yet, necessary.

1.3 Recommendations

The allotment of effort and expense in a monitoring case study of a large number of low-rise residential units may not be justifiable when compared to the apparent value of the information obtained therein, unless the scope of the investigation is limited to the measurement of a minimal number of precisely defined variables. Although the general benefits of re-insulation were clearly confirmed by observation in each of the study houses described in this report, the dominant revelation was the atypicality of any house, any wall, or any point on a wall. In addition, the extent of each re-insulation project was unique. As a consequence, definitive conclusions cannot be stated, and there prevails an impression that more information ought to have been

acquired. With the above in mind, a two-level approach to future studies of re-insulation or other retrofit projects is recommended.

To obtain an understanding of the effects of a major physical alteration to a building, such as the upgrading of wall insulation, an intensive before-and-after program of monitoring in a small number of carefully selected houses is suggested. This could be an expanded version of the current study, with improved temporal and spatial coverage of some variables. To this end, multi-channel recorders could be invaluable for standard temperature, moisture, and barometric-pressure measurement, and in decay heat loss experiments and the study of the movement of the neutral pressure plane.

Selection of study houses would be the major problem, the intent being to characterize the effects of typical work in existing Canadian housing stock. It may be appropriate to choose several houses of common design, age, and condition. In this way the very specific results likely to be obtained could be verified, and the individual result-biasing peculiarities of each house could be recognized and isolated. If particular problems resulting from retrofit measures are discovered, then these could be studied more specifically in the context of a wider variety of houses.

The second level of investigation suggested as a follow-up to the current study is one in which a large number of houses, representing the full range of existing housing, is monitored for fuel savings due to implementation of energy-conserving alterations such as re-insulation. Because of the continuing nature of home-upgrading efforts and temporal changes in the habits of the occupants, long-term utility records may not accurately indicate the reductions in energy consumption which can be attributable to any one retrofit activity. The alternative which is recommended is the direct monitoring of furnace operation for short periods before and after the retrofit work is done.

With the assistance of the homeowners in taking readings from counting-timing devices of the type used in the current study, a considerable number of houses could be examined simultaneously and inexpensively. The increased benefits of a program of continuous recording would have to be weighed against the additional cost. Monitoring would, in any case, be restricted to the heating season, and allowances would have to be made in the subsequent analysis for such short-term effects as solar radiation, exterior winds, and occupant behaviour.

The re-insulation of older houses which contain no wall insulation and minimal attic insulation is generally acknowledged to be a reasonable investment. However, the effect of such actions on the building structure and heating system, and, hence, the heating bill, is not known with accuracy due to a lack of good qualitative and quantitative data. Therefore, in order to identify the effects of re-insulation on the house structure, interior environment, and heating system, the data-collection task described in this report was initiated. The work was also expected to provide information to better estimate the accompanying fuel saving, and to indicate opportunities for further study in this area.

The project comprised a field investigation of several variables in a sample of Winnipeg-area housing stock before and after the test houses were retrofitted by re-insulating both exterior walls and attics, or exterior walls only, using blown loose-fill glass-fibre or cellulose insulation. These variables included:

- interior relative humidities
- interior air and building envelope temperatures
- decay heat loss
- location of the neutral pressure plane
- airtightness
- steady-state furnace combustion efficiency
- furnace on/off cycling time
- long-term electricity and natural gas consumption.

Thermographic scans of the building envelope from the interior were employed to provide further indication of envelope performance. Completing the collected data on the energy-related aspects of each house was a description of envelope assemblies and occupant habits.

The actual results of the tests provide useful empirical data, but they should be considered to be indicative rather than definitive quantities because of the extreme diversity of housing stock which formed the sample and because of the uniqueness of the scope of each retrofit project. A preliminary analysis on a house-by-house basis is presented in this report for the six houses examined in the

study. The collected data, which are arranged by house as Appendices A to F, are suitable for use in more detailed analysis. With verification provided by the temperature gradients across the building envelope and the electricity and natural gas consumption, modelling of the energy balance for each house may be based upon the descriptions of occupant activity, heating equipment, and building envelope assembly.

It is anticipated that the single most important outgrowth of the program of monitoring described in this report will be application of the acquired knowledge to the design of further studies. Consequently the sections following have been organized to highlight the procedures and problems associated with the various tests and the management of the overall testing program.

A modelling of the processes contributing to the energy balance in a residential unit between the loads imposed by the below- and above-grade external environments and the supplies, which may include furnace heat, electrical energy, solar radiation and occupant production, requires, as a base, a detailed characterization of the energy-related components of the unit, including both physical and human factors. For the example group of study houses this information is presented in Appendices (A-F).1* "General Information", and Appendices (A-F).2 "Building Description". Figures (A-F).1 provide building layouts and dimensions.

The process of assembling the above data for each test house was considerably less than straightforward, due to the lack of standardization in earlier house construction practices, due to the great range of styles which appeared throughout the years up to about 1950 (i.e., the "older" housing which was the subject of this project), and due to the scattered changes and additions made since the time of construction. From this experience it is clear that completion of an energy audit** for certain homes may necessitate more than a single visit and discussion with the occupants. A high degree of auditor familiarity with a given building is often essential for the discovery of its idiosyncrasies. The homeowner may be able to supply pa . of the required information rapidly, but, despite his intimate experience with the house, his understanding of the energy-related processes therein may not be at a level which could benefit the auditor.

* Appendices A.1, B.1, C.1, D.1, E.1, F.1, referring to study houses A, B, C, D, E, and F respectively. The six appendices have identical formats.

** The term "energy audit" is used in this report to describe the cataloguing of all relevant data on the construction, insulation, heating plant, and occupancy of a house.

In the case of the six houses examined within this project approximately one person-day per house was required to compile the required data (e.g., for test house A, this information is included as Appendices A.1 and A.2 and Figure A.1). One could expect this time to decrease with experience, but some tasks cannot be avoided. For example, a significant number of measurements of envelope and exterior dimensions and an accompanying graphic representation are necessary, because a reasonably comprehensive characterization for computer-modelling purposes should require more than a simple box-like description of house shape.

Determination of RSI values for the envelope requires a careful inspection of each component, if practicable. In some cases access is not possible and the homeowner can provide little information, so that estimates must be used. These may be based on other assemblies in the same house and similar components in other houses. The material and sub-assembly RSI values used in Appendices (A-F).2 were taken from Tables 3.2 and 12.1 of the CGSB Handbook on: Insulating Homes for Energy Conservation[1]. Integrated values for typical assemblies were not employed because most of the components encountered were "atypical". It should be noted, in summary, that, as all the base RSI values used are themselves only approximations, the values for complete assemblies can be estimates at best. For consistency, therefore, a sanctioned table of base values should be available to auditors and analysts. Table 3.2 of the CGSB Handbook on: Insulating Homes for Energy Conservation[1] could be expanded and clarified for this purpose.

[1]. Handbook on: Insulating Homes for Energy Conservation, Canadian General Standards Board CGSB 51-GP-42MP, Ottawa, July 1980.

4.1 Central Air Temperatures and Relative Humidities

Home comfort is perhaps best described in terms of air temperature and relative humidity. With the imposition, through re-insulation, of increased airtightness and thermal resistance at the building envelope, changes in these parameters may be expected. In order to characterize the interior environment of each test house during periods preceding and following the re-insulation, measurements of air temperature and relative humidity were made on a day-to-day basis near the centre and near the mid-height of the main floor level. The homeowner, using an inexpensive instrument (Springfield No. 1803) which includes a dial thermometer and analogue hygrometer, was requested to make periodic readings. Occasional benchmark values were determined by the project team using a Bacharach Sling Psychrometer (No. 12-7012) and psychrometric charts. The collected data are shown in Tables (A-F).3.

Interior air temperatures during the heating season are largely dependent upon thermostat settings which can be expected to be varied throughout the day and from day to day. Records of these temperatures can, however, indicate changes in occupant habits, which is important in a study such as this one where the effects of one alteration (e.g., re-insulation) are of interest, or they can reveal nonhomogeneities, which can be a major problem in data which are being collected beyond the control of the analyst. In this project, for example, the retention of heat distributed to inhabited rooms remote from the vicinity of the furnace was increased by the re-insulating of test house A (Table A.3). The reaction to increased temperatures in these rooms was an overall reduction in thermostat settings by the occupants. Another abrupt change in room temperature levels, shown in Table B.3, was attributable to a change in thermo-hygrometer location which was made by the homeowner near the end of the test period.

In one of the six cases, test house D, the thermostat setting was maintained at 22.8°C throughout the monitoring period. Twice-a-day-

recorded interior air temperatures at the thermo-hygrometer location (half way between the north exterior wall and the thermostat, which is centrally positioned on a partition wall) averaged 0.4°C higher after re-insulation. The change appears clearly in Table D.3 as an abrupt increase superimposed on a relatively steady temperature level, and it is thus an indication of an alteration to the thermal gradient across the interior air space. The effect of re-insulation upon thermal gradients across the envelope is more noticeable and is discussed below in connection with wall and ceiling surface temperatures.

Interior relative humidity may be expected to increase in response to the improved airtightness caused by the placement of layers of insulation at the building envelope. According to the thermo-hygrometer data in Tables (A-F).3, five of the six study houses did experience higher humidity after re-insulation. A summary of the phenomenon is presented in Table 1, in which the degree of increased humidity roughly parallels the fraction of the envelope retrofitted with insulation. Test house D, for example, is a bungalow retrofitted in the walls and attic, while test house C, also a bungalow, had insulation blown into the walls only, with the existing attic insulation being minimal. A slight decrease in humidity levels occurred in test house E.

Table 1. Air Temperature and Relative Humidities Before and After Re-insulation

Period	Before		After	
Test House	Temp.*	R.H.**	Temp.	R.H.
A	23.8	37.8	18.2	46.3
B	19.9	45.7	21.2	50.1
C	22.4	49.7	22.5	50.9
D	22.2	48.4	22.6	54.4
E	19.4	57.7	19.7	55.8
F	21.3	34.3	20.5	41.9

* °C, average calculated from Table (A-F).3, Col.2.

** %, average calculated from Table (A-F).3, Col.3.

Influences other than re-insulation of walls and ceilings may also have contributed to variations in interior-air moisture levels over the monitoring period. Changes in occupant behaviour may have occurred, but climatic conditions, which affect human activity in addition to the moisture content of interior air, remained unusually constant throughout most of the two months of field testing. The major interruptions to clear skies and slightly below-freezing temperatures were mild, rainy days on March 29 and 30, 1982, which resulted in the brief elevation of interior humidity levels in test houses C, D, E, and F, and warm spring days beginning April 11, 1982, at the end of the testing program.

Considerable differences are evident in Tables (A-F).3 between the humidity levels obtained with the sling psychrometer and the thermo-hygrometer. Because the former is usually the more accurate instrument, the results shown in Table 1 should be accepted with some caution. Too few psychrometer readings were made to allow conclusions to be based upon them alone, however, or to allow calibration of the thermo-hygrometers. The reason for this is the effect of occupant activity, which can be seen in the uncalibrated, continuous humidity data collected incidentally during decay heat loss testing (Section 5 of this report). Variations throughout the day of 5 to 25 percent in interior relative humidity are indicated in Figures (B-F).2 and (C-F).3. It may be, in addition, that significant differences occur from room to room and within a room as the interior environment responds to the various influences which are contributing to the temporal fluctuations. Under these conditions spot psychrometer measurements, unless they are made frequently, are of limited value in the effort to characterize the time-behaviour of interior relative humidity.

The loss in accuracy which is a consequence of the replacement of recording hygrometry by more economical analogue means is unfortunate, but must be tolerated in a situation where many units are to be monitored simultaneously. There may, on the other hand, be situations in which the increased information obtained from a continuous record would be an important consideration. With the growing necessity for an understanding of the moisture-related effects of retrofit work, the issue

of the type of instrumentation required to determine moisture levels must thus be addressed as a part of the formulation of future investigations.

4.2 Near-Envelope Temperatures

The higher thermal resistances associated with insulated, as opposed to uninsulated, exterior walls and ceilings result in larger temperature differentials across the building envelope, and, given identical outdoor conditions, in higher interior temperatures near the envelope. Empirical evidence of the effects of the typical re-insulation work studied in this project on across-envelope temperature gradients and data which may be used to estimate actual RSI values are shown in Figures (A-F).4, which include wall surface temperatures at three elevations, near-wall air temperatures, and ceiling surface temperatures, each recorded both before and after re-insulation. Measurement locations are shown in Figures (A-F).1 (e,f), and outdoor conditions are given at the beginning of Appendices (A-F).3 "Test Results".

The values listed in Table (A-F).4 are readings taken from an Amprobe T-150 Thermometer with air probe RBT-13 or surface probe RBT-12 taped to wall or ceiling. Representative locations were chosen, away from studs and joists, warm-air outlets and points of air leakage. Solar effects were noticeable only for test house D in which west wall temperatures were elevated by the late afternoon sun during the "before" test, and for test house F which was similarly affected on the west and south (noticeably) sides of the upper level during the "before" test and the east side of the upper level during the "after" test.

An expected steepening of temperature gradients across the building envelope in response to re-insulation was generally observed in each of the study houses, but inconsistencies from wall to wall were significant. This may be demonstrated with the aid of the expression relating mean temperature differentials and thermal resistances within a structure, i.e.,

$$\frac{T_i - T_x}{T_i - T_o} = \frac{RSI_{ix}}{RSI_{io}}$$

in which T_i, T_o, and T_x are, respectively, the mean temperatures of the interior air, the exterior air, and an intermediate point x, and the right hand side is the ratio of the RSI value of the portion of the structure between the interior air and point x to the RSI value of the entire assembly.

For the north, east, and south walls of test house D before re-insulation, as an example, and with an interior air temperature, T_i, of 20.6°C (Table D.3, "03.19.13:30"), an exterior air temperature, T_o, of -2°C (Appendix D.3, p.D5), and a nominal RSI value of 0.63 for the wall assembly (Appendix D.2), the above expression yields expected temperatures of 16.3°C and -0.9°C for the interior and exterior wall surfaces, respectively, which represents a drop through the wall of 17.2°C. From Table D.4 and Figure D.1 it can be seen that, while the measured values at locations C and D verify the predicted value, the surface temperature at location E is significantly higher than the prediction. Vertical variations on each wall may be attributable to air movement in the cavities and to stratification in the living space. Similarly, with interior and exterior temperatures of 22.8°C and -6°C during the house visit after re-insulation, and with the nominal RSI value of the wall assembly raised to 2.17, the expected interior and exterior wall surface temperatures are 21.2°C and -5.6°C, respectively, the drop across the wall increasing to 26.8°C. In this case, the prediction is most closely matched in the field at location E, with locations C and D being cooler than in theory.

Several factors not explicitly accounted for in the surface-temperature relationship, nor addressed directly in field testing, may be acting in combination to produce the above-described discrepancies and similar results for the other houses of the study group. For example, an indirect solar effect, reflection from the south wall and roof of the house immediately north of test house D, may be partly responsible for the elevated temperatures at wall location E during the pre-retrofit house visit, which occurred in the afternoon of a sunny day. Diffused flow from a

nearby floor-mounted, warm-air outlet may also increase the interior surface temperature of the north wall. Construction details and conditions may not be the same throughout the house, thus contributing to the differences from wall to wall at any one time and to errors in the estimation of thermal resistances. The latter may be heightened by slight nonuniformities in the in-place density of the blown-in wall insulation. Biases beyond those mentioned are likely.

Perceptible draughts along the exterior walls, before the stud cavities were filled with insulation, appeared to cause some slow undulation in wall-surface and near-wall air temperatures. Commonly the amplitude of such fluctuations was of the order of 1°C. This condition diminished considerably once the wall cavities had been filled, which may be interpreted as being an indication of increased airtightness and thermal mass in the walls. Intermittent operation of the furnace fan, producing periods of alternating destratification and stratification, may also contribute to the observed temperature undulations.

It is clear from this discussion that considerable variation in performance can be found over a single wall surface of nominally uniform construction. A few representative monitoring locations may be chosen, as with the program applied in this study, but the lack of standardization in building practices and uneven aging (including damage) probably ensure that a range of conditions will appear on each wall section of an older home. For future investigations of this type, therefore, it may be useful to define a more extensive network of temperature monitoring locations within each house, and, to mitigate the associated increase in time allotted and expense, it may be appropriate to monitor a sample of houses which are fewer in number but more carefully selected to meet the purposes of the subsequent analysis.

Two indicators of overall performance of the residential unit are the rates at which the interior achieves an equilibrium with the outdoor environment when energy inputs are removed and the rate at which the interior is warmed while energy is being added. Much may be learned from controlled experiments of this type when standardized structures and contents are used. Unfortunately only limited information is likely to be gained from such tests attempted in occupied housing, a category which includes most of the dwelling units in Canada, because it would be unusual for the analyst to be granted unconstrained control over the house environment.

The procedure in general comprises the monitoring of interior temperatures over time with the main heat sources either turned off or operating. Periods of several hours to a few days in length are thus required in order to ensure a significant range of observed temperature. The occupants obviously cannot be expected to tolerate disruptions of this magnitude. A reduction in experimental scope, however, may be practicable as experience in this project has indicated.

Simple decay heat loss tests were executed before and after re-insulation in the study homes. In each case air temperature was recorded continuously, using a Brown Instruments No. 612X21 Thermometer, near the centre of the main level of each house approximately 1 to 1.5 m above the floor, and over consecutive periods with the thermostat first set at the normal household operating level, then at its lower limit, and then again at the normal level. The tests were carried out overnight and in the absence of the occupants, if possible, in order to minimize perturbing influences such as solar gains, the use of electrical appliances, door openings and closings, and biological heat production. Base-load appliances such as refrigerators and water heaters were left running during the tests. Results are presented in Tables (A-F).7 and summarized in Table 2, with the original charts given as Figures (B-F).2 and (C-F).3. The rate of decrease of the interior air temperature depends on the outflow of heat from a number of components, each with its own characteristic thermal inertia, and on the effectiveness of the envelope as a barrier to heat

flow. Stratification in the absence of forced interior circulation during the test could be expected to be a further complication. Windspeed variations may also be important. A simple exponential decay, in which the rate of change of interior temperature is proportional to the temperature differential across the envelope using an effective thermal inertia of the house and an effective envelope loss coefficient, is therefore unlikely to be an adequate descriptor, particularly in older houses in which air leakage is as significant as conduction as a mechanism of heat loss.

The above is apparently confirmed in Tables (B-F).7 and Table 2 which indicate clearly, for the first several hours of decay, that the dominating influences over the rates of temperature drop shift from components of low thermal inertia (e.g., the interior air itself) to those which release heat more slowly. Resolution is limited in the current results, however. Further empirical study and analysis are thus necessary to determine if distinct points of transition can be identified in the interior temperature traces resulting from decay heat loss tests.

It is possible to infer and compare the thermal performances of houses from decay heat loss test data if a useful indicator is defined. The relative cooling rates which have been extracted from interior and exterior temperature records for the test periods, and which are given in Tables (B-F).7 and Table 2, are representative of the overall heat-retaining capabilities of the structures, but they must be treated as series of values when used in comparisons among houses because of the time dependence discussed above. Some uncertainty in the data is due to variations in occupant activity and to unnoticed differences in test conditions. In general the bungalows (test house C and D) appear to cool less rapidly than the taller houses, behaviour which may be attributable to the smaller influence of the stack effect as a driving force for air leakage. Forced interior-air circulation was maintained during the tests in study house F. It is also evident from the tables that re-insulation reduced the rate of cooling in all cases.

Table 2 Decay Heat Loss Test Results Before and and After Re-Insulation

Test	Before		After	
Test House	k_{0-1} *	k_{3-6} **	k_{0-1}	k_{3-6}
B	-	-	.0696	.0316***
C	.0878	.0348	.0146	.0225
D	-	.0426	.0400	.0229
E	.0689	.0482	.0701	.0387
F	.0910	.0380	.0647	.0279

* Relative cooling rate (h^{-1}) for the first hour of the decay heat loss test, formed by dividing the interior air-temperature drop by the average interior/exterior air-temperature difference over the hour.

** Average relative cooling rate (h^{-1}) for the fourth through sixth hours after the start of the decay heat loss test.

*** k_{3-4}; test house B only.

The potential usefulness of decay heat loss observations having been demonstrated above, more useful indicators and a standardized procedure are clearly warranted. Any test designed for use in occupied housing, however, must not contribute to a perception of loss of freedom for the residents, yet must ensure spurious results are not generated by occupant activity. Once consistent and reliable inferences can be formulated from a decay heat loss test, its real value as an analytical tool will become assessable.

Air leakage is a major contributor to the high energy consumption and moisture problems which may be experienced in older residential housing stock. The main driving forces are indoor/outdoor pressure differentials and wind action. Measures proposed to mitigate the outward movement of moisture past inadequate vapour barriers and into insulating and structural materials have included the maintenance of a negative pressure differential over the entire building envelope. The severity of such measures depends on the effort required to lower ambient indoor pressures enough to ensure infiltration on all walls and ceilings. Absolute pressure differentials across the envelope are slight, so their determination is quite difficult, but the detection of relative differences and, hence, of the points of neutral pressure, is a simple exercise requiring on the order of fifteen minutes work with smoke pencils.

Neutral pressure planes were located in the six study houses before and after re-insulation, and with the furnace and fan operating and turned off. The direction of movement of smoke released (using Drager Air Current Tube CH216) along the interior side of the building envelope near cracks, joints, doors, windows, and attic access points was observed in order to define points of infiltration and exfiltration. With this approach little difficulty was experienced in accurately locating the level of neutral pressure on each exterior wall. This success may be attributed partly to the insignificant effect of wind pressure variations during the tests. The mature urban environment in the neighbourhood of each house contributes to a near-surface damping of large-scale air movements, with the result that winds impinging upon the building envelope are usually light. Windspeeds recorded at the time of the test visits, as shown in Tables (A-F).5, ranged from 3 to 8 km/h. With the stack effect therefore as the dominating control, infiltration, exfiltration and the points of neutral pressure remained quite steady during each test. In most cases, as indicated in Table 3, which is a summary of information from Tables (A-F).2, the neutral pressure plane was found to lie near the upper ceiling, regardless of the number of storeys.

Table 3. Neutral Pressure Plane Location Before And After Re-Insulation

House and Description	Time Furnace	Before off	Before on	After off	After on
A (1½ storey - side attics)		at ceiling	at ceiling	at ceiling	at ceiling
B (1½ storey - no side attics)		upper level mid-height	upper level mid-height	above ceiling	above ceiling
C (bungalow)		at ceiling	above ceiling	above ceiling	above ceiling
D (bungalow)		at ceiling	slightly higher	at ceiling	above ceiling
E (1½ storey - side attics)		at ceiling	at ceiling	at ceiling	slightly higher
F (1½ storey - side attics)		at ceiling	above ceiling	at ceiling	above ceiling

The rise in the elevation of the neutral plane with operation of the furnace, as a demonstration of the effectiveness of an induced exhaust in reducing interior pressure, was not as marked as originally anticipated. This may be attributed to the heated column of air persisting in the masonry chimney through on and off cycles, thus causing a relatively continuous draught rather than one which operates only when the furnace is on. The effect of re-insulation was minimal, with only two of the six houses (B and C - both with wall re-insulation only) showing significant change. The level of the neutral plane rose in both cases.

The location and direction of air leakage is easy to detect. Extensive use of the neutral pressure plane test could provide valuable information for the designers of envelope pressure-differential control measures. Both equipment and manpower costs are minimal, so that such data could also be collected from many houses as a part of larger and diverse monitoring efforts. A secondary use could be as a visual aid in the explanation of the mechanisms of infiltration and exfiltration as a part of homeowner

energy-education programs. Quantification of the air leakage capability of a house is the subject of the next section.

Reduction of air leakage has been recognized as a highly cost-effective component of residential energy conservation. Along with airtightening philosophy and techniques, the procedures and equipment for the measurement of the air-leakage characteristics of the building envelope have been developed and well refined over several years. The CGSB Standard (No. 149-GP-10M) "Determination of Airtightness of Buildings by the Fan Depressurization Method" is, at the time of writing, in draft form. A number of airtightness testing units are currently in use. It has thus become possible to perform and compare routinely the results of airtightness tests for residential dwellings.

For this project, two airtightness testing units were employed, one foldable assembly developed by UNIES Ltd. (referred to as Type A) which fits and may be sealed into standard-size door openings (81 cm x 203 cm), and one developed by Ener-corp Management Ltd. (Type B) which utilizes a size-adjustable and sealable aluminum door frame with three attachable panels. Each unit includes an electric blower which exhausts air out of the house through a bell-mouth nozzle to produce a net pressure differential between the interior of the house and the outdoor air. A vertical manometer attached to the nozzle is used to determine the exhaust-air flow rate and an inclined manometer measures the indoor/outdoor pressure differential.

The ability to adapt an airtightness testing unit to a range of dimensions of door opening is an asset when working with housing stock erected before the advent of standardized door sizes. Some doors have, in addition, been mounted close enough into corners on either the interior or the exterior side that full access to the opening is prevented. A second major consideration noted during the field work for this study is the capability of the airtightness testing unit to generate sufficient pressure differentials and fan speeds to be useful over the wide range of airtightness likely to be encountered in older housing.

The CGSB standard procedure was followed during this project, with one consistent variation: only a

single external pressure tap was used, that being at the location of the airtightness testing unit. It is considered that the use of multiple taps would add undue complexity to the airtightness test, especially in cases of low wind pressures. Any other deviations from the standard procedure are noted in Tables (A-F).5, which show the results of airtightness tests for the study houses. Some of the more interesting findings are presented below in Table 4.

Table 4. Summary of Airtightness Test Results

House	Volume	Air Changes/ Per Hour (10Pa)		Relative Tightness* (cm^2/m^2)		
	m^3	Before	After	Before	After	%Change
A	406	3.74	2.91	6.33	4.88	-22.9
B	505	2.70	1.84	5.68	3.81	-32.9
C	352	2.11	1.74	4.67	3.79	-19.1
D	326	2.07	1.47	4.31	3.06	-29.2
E	303	2.92	2.79	5.11	4.87	- 4.6
F	303	5.07	4.15	8.81	6.83	-22.5

* Equivalent Leakage Area (at a differental pressure of 10 Pascals) divided by the contributing, above-grade, building-envelope area.

The significant increase in airtightness for most of the houses in the sample is most probably a direct result of the substantial reduction in freedom of air movement in the wall cavities. The effects of the insulation appear to have been somewhat lessened by a decrease in resistance to flow through the outer skin (stucco) of houses C and E whose wall-cavity access holes had not been sealed by the time of the "after" tests. It is the policy of some insulating contractors to wait until the arrival of warm weather (+10°C) before patching the stucco in order to ensure the setting of the patching compound. As this interval could be of the order of months in some cases, the reduction in the effectiveness of the added insulation and the risk of exposure to moisture could be significant (the plugs used in the holes do not fit tightly as a rule because of the difficulty of drilling a tidy hole through the stucco-sheathing combination).

The stucco of test house E was patched late in May, 1982. The results of a subsequent airtightness test are shown in Table E.5. Any improvements in airtightness parameters which may be attributed to the patching of the exterior of the house are not readily apparent in the results. Seasonal and other variations in the condition of the house and possible differences in the execution of the test would seem to have had more effect.

Access to the wall cavities for houses A and B was from the interior, and all holes were well patched and sealed afterward. The outer stucco of house D was patched promptly following re-insulation, and horizontal siding was removed and later replaced on house F. The plugs used in the latter case fit tightly into the access holes which were cleanly drilled through sheathing only.

Table 5. Breakdown of Airtightness Test Results for Test House F

Component	Original	Addition	Total
Volume (m^3)	283	20	303
ELA_{10}*(m^2): before	0.155	0.0297	0.185
: after	0.135	0.0084	0.143
: % change	-13.1	-71.6	-22.5

* Equivalent Leakage Area at a differential pressure of 10 Pascals.

A poorly sealed joint between the added-on back room of test house F and the original structure was a major contributor to air infiltration. Air able to penetrate the wall system at the joint was transported via empty wall cavities to interior points of entry into the room. Table 5 indicates the relative importance of this room to the overall airtightness of the building (in addition to the standard test, a second test was performed both before and after re-insulation with the airtightness testing unit located in the doorway linking the back room to the original building). The three outer walls of the addition were not altered between the two sets of tests, because they already contained RSI 1.4 fibreglass batts. Only the stud cavities of the fourth wall (the wall in common with the original structure) were retrofitted by

re-insulating with blown loose-fill cellulose insulation. This measure, as shown in Table 5, was highly effective in reducing the concentrated flow of air into the room.

Much of the difficulty and ambiguity having been eliminated from the airtightness test through standardization, it can now be employed inexpensively, as in this project, to evaluate the overall capability of the building envelope to resist air leakage. It will thus be, for retrofit studies, a most useful tool with which to quantify some of the effects of certain energy-conservation measures.

The prime indicator of the effectiveness of conservation measures is, of course, the energy consumption. For retrofit projects involving re-insulation most of the directly attributable improvement in building performance will be noticeable in the heating fuel bill. With increased airtightness and reduced heat transmissivities, the shorter and more infrequent burns may be expected to contribute to a reduction in overall energy conversion efficiency of the furnace, but this will in most cases be masked by the significant overall drop in fuel consumption.

A summary of energy-use statistics for the study houses of the project is presented in Table 6. Long-term energy consumption records were obtained from the appropriate utilities for the period January 1980 to the present, and are included as Tables (A-F).8 for natural gas and (A-F).9 for electricity. Consumption will be monitored through the 1982-83 heating season, and the data will be submitted when available.

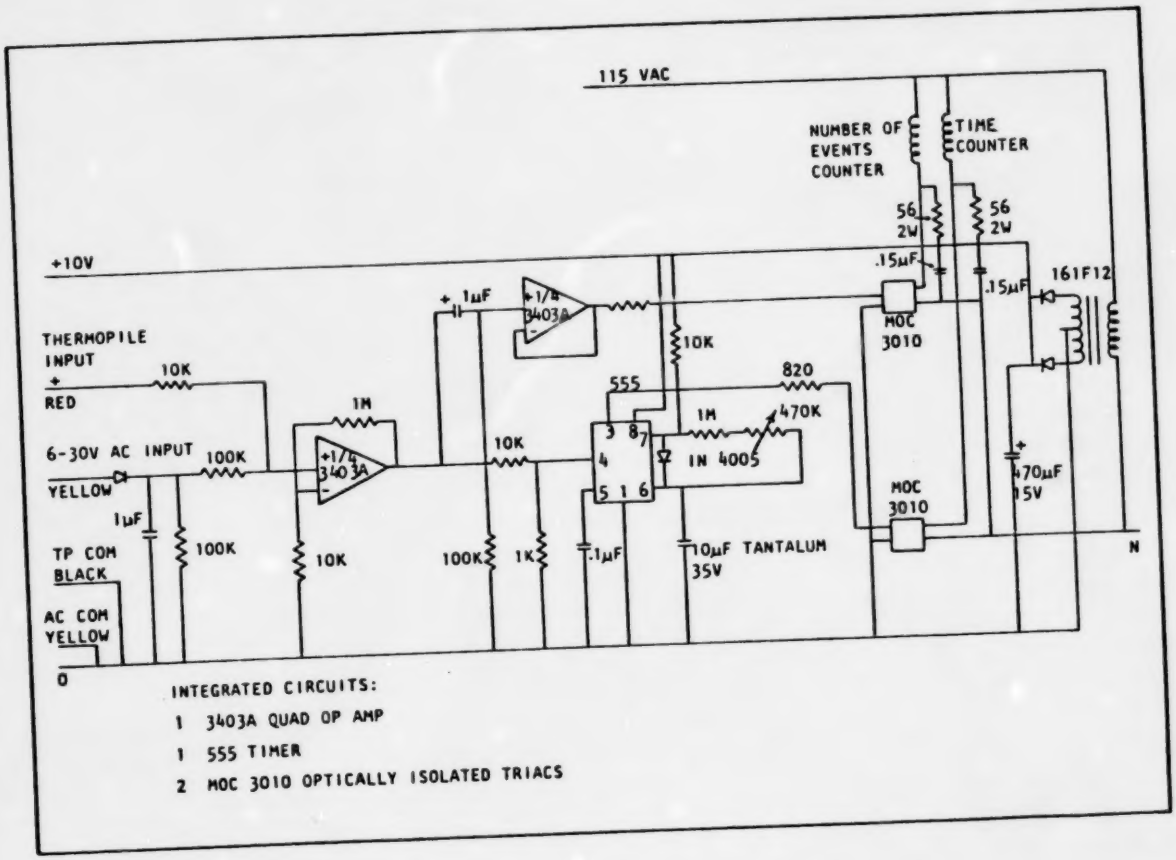
Steady-state furnace combustion efficiency was determined both before and after re-insulation to detect any obvious changes in the condition of the equipment. All units are older, and are of various sizes, as indicated in Appendices (A-F).1, but are operating with approximately the same efficiency despite the range of levels of care. As shown in Tables (A-F).1 not much change occurred between the "before" and "after" tests. Combustion efficiency was determined from measurements made of steady-state flue-gas temperature and CO_2 content, using a Bacharach Tempoint Dial Thermometer (No. 12-7014) and a Fyrite CO_2 Analyzer (No. 11-7032). Each test for CO_2 content was performed twice for verification.

Table 6. Energy Consumption Before And After Re-Insulation

Test House:		A	B	C	D	E	F
Vol. of Heated Space (m^3):		406	505	352	326	303	303
Electricity Use (kWh):							
	1980	7481	7836	7321	6590	5385	8300
	1981	7009	7608	6766	6250	5051	7560
Natural Gas Use (m^3):							
	1980	5734	4831	3338	4822	4120	5499
	1981	5224	4661	1993	4822	3624	4791
Combustion efficiency (% avg):		67.5	72.5	66.8	70.0	74.5	73.5
No. Cycles per Degree-Day (D-D):							
	before	1.34	1.61	1.44	4.19	1.30	15.2
	after	1.40	1.24	1.31	2.63	1.09	12.9
	% change	+4.4	-23.0	-9.1	-37.3	-19.5	-15.0
Burn Time (s/D-D):							
	before	915	783	841	924	511	1274
	after	554	570	705	550	463	1030
	% change	-39.4	-27.2	-16.2	-40.5	- 9.2	-19.1

The frequency and duration of furnace operation were measured with a furnace monitor designed by UNIES Ltd. The device, illustrated in Figure 1, consists of two event counters and circuitry which, when wired across the solenoid valve on the natural gas line in the furnace, register the number of times the valve is actuated and the total time elapsed (in units of ten seconds) while the valve is open. In the configuration employed for this project the monitor is read manually at intervals long enough to average out short-term fluctuations caused by, for example, human activity, but short enough to indicate trends. One to four observations per day by the homeowner proved to be an ample number for characterization of furnace operation in the study houses under pre- and post-retrofit conditions. As summarized in Table 6 and detailed in Tables (A-F).6, a significant and consistent reduction in burn time per degree-day accompanied each re-insulation project.

Figure 1 Schematic of Furnace Monitor



Similar fuel savings in each of the retrofitted houses may be expected over the longer term, although it should be remembered that solar gain varies throughout the year and wind velocities affect the rate of heat loss. Therefore burn time per degree-day will exhibit some variation with the season and day to day. The monitoring of furnace operation in this way, however, is a rapid and inexpensive means of evaluating the effectiveness of energy-conservation measures.

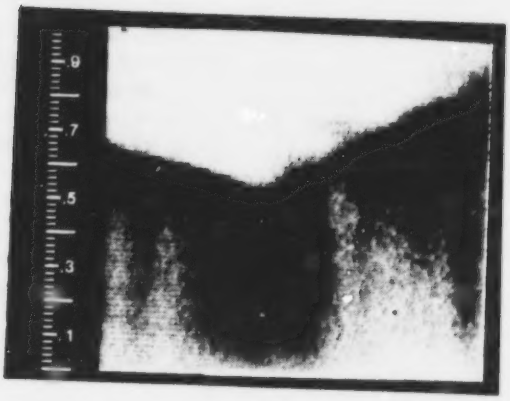
Problem areas in the building components, including weak or missing insulation, moisture, and air infiltration can be detected and recorded easily and rapidly by an experienced analyst using infrared technology. Thermographic scanning may be useful in single-phase retrofit projects, such as those examined in this study, to document the changes in the above energy-related variables which are directly attributable to a particular retrofit activity. In order to assess the usefulness of the technique, thermographic scans of the building envelope from the interior were included as part of the before-and-after field testing program. The infrared photography and interpretation were performed by Thermal Energy Consultants, Inc. of Winnipeg. Representative examples of the results for each test house are presented in Appendices (A-F).5 "Thermography".

Moisture problems above grade in the building envelope are not a common occurrence in older housing stock in the Winnipeg area. Infrared scanning prior to re-insulation revealed no evidence of moisture in the exterior walls or ceilings of any of the study houses. Visual inspection of the undersides of the roofs in some of the attics did indicate the historical presence of condensation, although all roofs were dry when observed. Recent increased public awareness of the necessity for attic ventilation and subsequent action by some of the homeowners in conjunction with attic re-insulation projects may have mitigated attic-moisture problems in these houses, but the combination of the lack of a vapour barrier and the filling of the stud cavities with loose-fill insulation may, in future, contribute to an increase in moisture levels in the walls. The post-retrofit thermographic scans, as could be expected, showed no immediate moisture build-up.

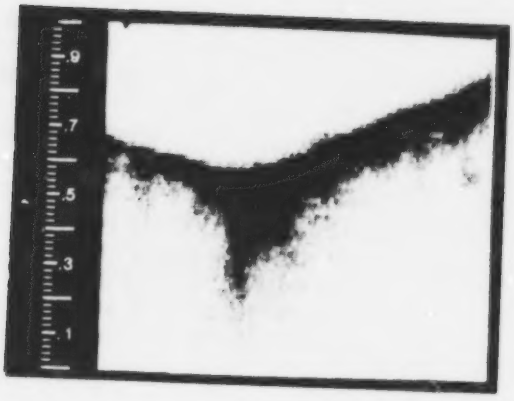
As a check on the effectiveness of the blown-in method of wall re-insulation, thermography proved to be an invaluable aid. Without disturbing the interior or exterior finishes, the absence of insulation could be detected fairly easily by means of a visual examination of relative envelope temperatures. A typical before-and-after comparison of several wall cavities in one of the study houses is given as Figure 2. The uniformity in the

Figure 2

Thermal Images of Exterior Walls and Ceiling Before and After Re-insulation of Walls: (a) Before; (b) After.



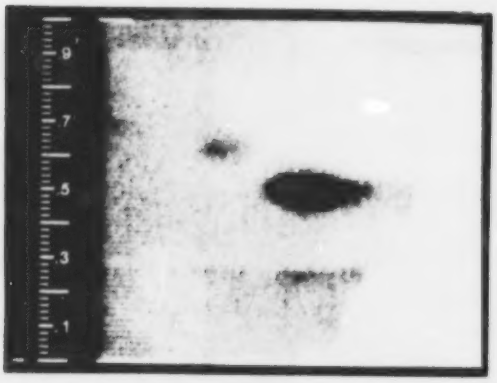
(a)



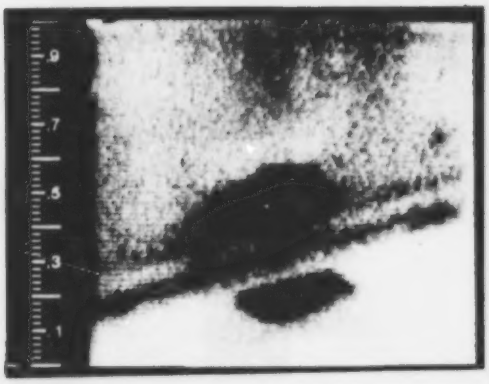
(b)

Figure 3

Thermal Images of Hidden Problem Areas:
(a) Remains of old plumbing stack;
(b) Location of old wall register.



(a)



(b)

Figure 3 (continued)

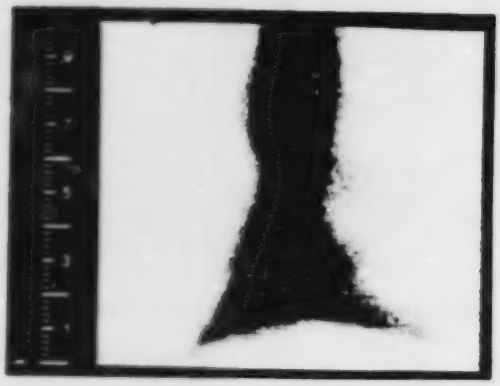
Thermal Images of Hidden Problem Areas:
(c) Incomplete insulation of kneewall;
(d) Cold joist spaces.

(c)

(d)

Figure 4

Thermal Images of Infiltration and Migration at Junction of Two Exterior Walls: (a) Before re-insulation of Walls; (b) After re-insulation.



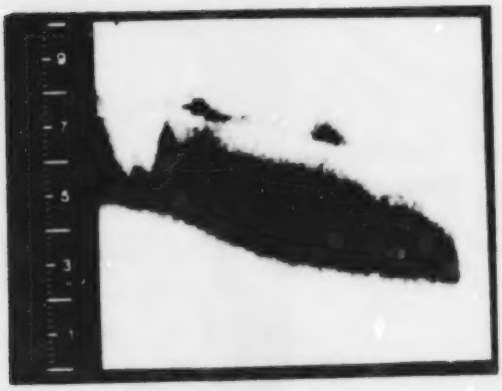
(a)

(b)

Figure 5

Thermal Images of Infiltration at Sill Plate: (a) Before re-insulation of walls; (b) After re-insulation.

(a)



(b)

Figure 6

Thermal Image of Air Leakage at Attic Hatch.

insulation which is exemplified therein was general throughout the scanned houses. None of the obvious exceptions involved variations in density which could be related to the technique of emplacement.

Hidden changes to, or design problems with, the original structure were quite often discovered during the scanning of the envelope. Figure 3(a), for example, reveals the former point of ceiling penetration for a plumbing stack. In Figure 3(b) evidence is shown of the replacement of wall registers with floor units prior to an overlaying of original plaster walls with drywall. Incomplete coverage of second-floor kneewalls with glass-fibre batts is indicated clearly in Figure 3(c). Cold air in the joist spaces, shown in Figure 3(d), is attributable to the combination of exterior wall types incorporated into the building, i.e., wood-frame above double-brick, with the outsides flush. The joist spaces are open, at the perimeter of the house, to the cold brick walls upon which the joists bear.

Poorly finished alterations and design faults such as the above may, along with the effects of age and wear, be unrecognized obstacles to the realization of the benefits of re-insulation with loose-fill material. Thermography in this context is extremely useful as an educational tool, because the results (photographs) are tangible, they illustrate the specific problems associated with each house, and they clearly demonstrate that re-insulation may be complemented by other energy-conservation measures, particularly the reduction of air leakage.

All the houses, for example, yielded clear evidence, via the infrared scans, of the penetration of cold air from the exterior, its migration within the structure, and its entry into the interior living space. Figures 2, 4, and 5 show the effect of leakage (induced during the scans by means of a negative pressure differential of 15 Pa imposed on the house) in the vicinity of top and sill plates, and the decrease in air movement in the wall system caused by the addition of insulation. No direct attempt having been made, at the time, to eliminate the flow paths, serious air-leakage problems remained in the houses after re-insulation,

including major leaks at intentional openings in the envelope such as attic hatches (e.g., Figure 6), doors, and windows. In many cases programs of sealing and weather-stripping could be as effective as re-insulation in reducing the energy consumption. The motivation for such action could be induced in the homeowner with the use of thermography.

The preceding sections have included discussions about the procedures and problems associated with the measurement of several variables within a before-and-after study of retrofitting older houses by re-insulation. If carefully ordered, most of the work could be carried out within several hours during a single visit to each house by two project team members and one thermography consultant with two house visits per day handled comfortably. Temperature, humidity, neutral-pressure-plane, and furnace-efficiency testing were scheduled before the thermographic scans and airtightness tests (three to four hours required in total) in order to be representative of the normal building environment. The installation and operation of the airtightness testing unit tended to increase the flow of cold outdoor air across the building envelope and into the interior. Decay heat loss experiments were arranged for other occasions when the interior environment could be considered to be stabilized under normal operating conditions.

A study such as this one, however, is necessarily more than merely a number of data-gathering forays. The social component of the research program may easily be underestimated, because it may not be expected to provide much tangible information. Housing is, in perspective, a dominant factor in the lives of most Canadians and consequently is a subject of great interest and discussion. A good rapport with the homeowner is thus easily cultivated, and is essential when frequent access during the monitoring period must be granted. In addition, the subtle peculiarities of each house which are relevant to analysis of energy-related variables may be more quickly noticed by the analyst through extended discussion with those who know the house well in a qualitative way. An explanation of results and suggestions for home improvements may, in return, be of considerable satisfaction to the homeowner.

A particular problem in the design of home-retrofit studies is the lack of control over the timing of, the nature of, and the location of the work to be investigated. Without the availability of time to await the occurrence of retrofit projects exactly meeting requirements, compromise in choice of test

units may be an appropriate alternative. A financial inducement may, however, be effective if the project involves the committment of capital on the part of the homeowner and this is the only deterrent to immediate action.

The present project, for example, was an investigation of typical re-insulation work in Winnipeg-area houses during a period (early 1982) when activity within the home-insulating business was minimal. Contractors expressed the opinion that two major factors were involved: the general slowness of the economy, and the fear of the uninformed homeowner in response to publicity surrounding the urea formaldehyde foam insulation problem. It soon became clear after commencement of the project that the choice of test houses would be limited.

Word-of-mouth advertising of the project proceeded with the aid of the following groups: the Province of Manitoba Energy Information Centre, the Conservation and Renewable Energy Office of Energy, Mines and Resources Canada, the Canadian Home Insulation Program Office, and the Manitoba Insulation Contractors Association and, in particular, some of its more active members. Discussion was also initiated with officials of Manitoba's Home Insulation Loan Program which is administered through the electric utilities. Only a few possible test houses were uncovered through the above channels (one was suitable for study), with re-insulation of attics only or basement walls only being the dominant on-going activity.

Future re-insulation of above-grade walls was being actively planned by some homeowners, but the weather and financing were reasons stated for delaying the work. In order to precipitate an early decision in such cases, and thus create possible study houses, a payment to participating homeowners was offered. Notification of this offer was placed in the first section of the local Saturday newspaper (Figure 7), thus ensuring wide circulation, and a number of insulating contractors were informed directly. Approximately twenty responses to the advertisement were received over a two week period from which one test house was identified. The insulating

Figure 7

Newspaper Announcement of Retrofit Study

HOME INSULATION RESEARCH PROJECT

UNIES LTD., CONSULTING ENGINEERS

UNIES Ltd. wishes to contact homeowners who are planning to have their houses insulated before the end of March, 1982 and who would be interested in participating in a research project to determine the effects of this work. Measurement of energy-related variables during a visit to each house before and after the insulation work is done is the major component of the project, with final visits to be completed by early April, 1982.

THOSE HOMEOWNERS PARTICIPATING IN THE STUDY WILL RECEIVE A PAYMENT OF $250.00 FOR THEIR ASSISTANCE.

To qualify, houses must:

a) not contain any wall insulation at present,
b) have the new insulation applied in the walls only or in the walls and attic only,
c) be heated with natural gas or oil.

Homeowners who would like to participate or who require further information are asked to call Cam McInnes or Gary Proskiw of UNIES Ltd. at 633-6363 as soon as possible.

contractors, eager to incorporate the possible payment for participation into their effort to stimulate business, were responsible for locating approximately six additional units of which four could be scheduled for testing within the allotted time period. In total, six houses generally meeting the requirements of the study were chosen for monitoring.

The concept of a before-and-after field study of home-retrofitting activities is thus a workable one. Field-testing difficulties can largely be mitigated with experience. It may, however, be necessary to allocate a disproportionate amount of time to the identification of test homes. Advertising of the project should be organized to maximize exposure in cases in which the numbers of possible study houses are likely to be minimal or study specifications are strict. Finally, good relations forged between the project team and the homeowner can be beneficial to the overall progress of the study.

APPENDICES

A. Study Data - 261 Landsdowne Ave.

B. Study Data - 107 Newman Ave. W.

C. Study Data - 353 Chalmers Ave.

D. Study Data - 460 St. Jean Baptiste

E. Study Data - 822 Talbot Ave.

F. Study Data - 380 Queen St.

A.1 General Information

Identification

Address:	261 Lansdowne Avenue, Winnipeg, Manitoba R2W 0G5

Residence Description

Type of Home:	Single, detached
Year of Construction:	1920 (estimated)
No. of Storeys:	One and one-half
Wall Construction:	Wood frame
Type of Foundation:	Basement
No. of Residents:	4 (divided into 3 suites)

Thermostat

Setting:	Day: 18.9°C* Evening: 18.9°C Night: 18.9°C (Manual)
Test:	Measured interior temp.: 20.6°C Cut-in: 18.9°C

Domestic Hot Water

Type of System:	Natural gas
Tank:	Capacity: 114 l Insulation: 25 mm
Measured Temp.:	68.9°C
Daily Use:	General: 45 l/person Washer: 15 l/person

Space Heating

Type of System:	Natural gas forced air
Furnace:	Bulloch's Ltd. AC-150-GLB (millivolt controls)
Age:	16 to 20 years (estimated)
Rated Specifications:	Input: 43.9 kW** Output: 35.1 kW**
Fan Operation:	Noncontinuous
Chimney:	Masonry, inside and adjacent to northeast foundation wall and along partition between kitchen and back room

Miscellaneous

Basement:	Temperature: 17.2°C Humidity: Dry
Dryer Venting:	Outdoors
Winter Humidifier Use:	Regular
Current Problems:	Draughts, cold rooms, restricted circulation and uneven heat distribution due to closed interior doors

* Unless otherwise indicated, all temperatures are conversions from field data recorded to nearest degree Fahrenheit. No further accuracy is implied.

** Conversion from nameplate specification in Btu/hr.

A.2 Building Description

Component: Assembly (approx.)		RSI[1] Before/After
Basement:		
Floors:	Poured concrete	4.4
Walls:	Poured concrete, 0.6 m above grade, 1.5 m below grade, uninsulated	0.8
Main Floor:		
Walls:	Outside air film	0.03
	Aluminum siding	0.12
	Softwood sheathing	0.17
	100 mm wall cavity: 15% structural softwood (RSI 0.87) with 85% air (RSI 0.18) or blown cellulose (RSI 2.50)	0.20/1.95
	Internal wall	0.17
	25 mm wall cavity: 15% structural softwood (RSI 0.22) with 85% air (RSI 0.18)	0.19
	Interior finish - lath & plaster	0.12
	Interior air film	0.12
		1.12/2.87
Doors:	Inner door with aluminum storm outdoor door	0.7
Windows:	Double pane	0.35
Front & Back Attics (vented):		
	Attic air film	0.08
	200 mm blown cellulose added	0/5.00
	89 mm joist space: 10% structural softwood (RSI 0.77) with 90% zonolite (RSI 1.42)	1.31
	Interior finish - drywall	0.08
	Inside air film	0.11
		1.58/6.56

[1] Tables 3.2 and 12.1, Handbook on: Insulating Homes for Energy Conservation, Canadian General Standards Board CGSB 51-GP-42MP, Ottawa, July 1980.

Component: Assembly (approx.)	RSI
Front Exposed Floor:	
Crawl space air film	0.08
63 mm fibreglass batts: 90% (RSI 1.39) with 10% joists (RSI 0.55)	1.21
Flooring	0.17
Tile	0.01
Inside air film	0.11
	1.58
Back Exposed Floor:	
Crawl space air film	0.08
Plywood sheathing	0.14
140 mm floor cavity with 10% joists	0.16
Plywood sheathing	0.14
Carpet, rubber underlay	0.23
Inside air film	0.11
	0.86

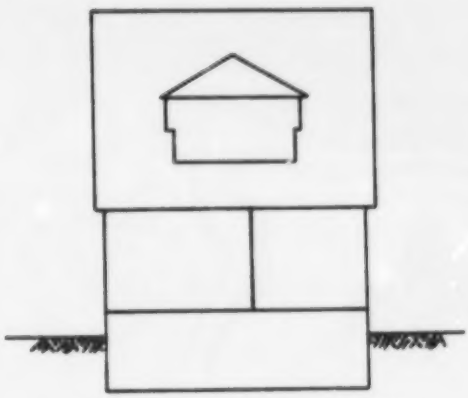
(Note: back crawl space temporarily insulated on inside walls with 50 mm expanded polystyrene; floor cavity to be insulated in 1982.)

Second Floor Walls (back, 2 sides):	
Same as main floor walls	1.12/(2.87, summer 1982)
Front Knee Wall (vented):	
Attic air film	0.08
Wall sheathing	0.17
100 mm wall cavity as in main floor walls	0.20/(1.95, complete summer 1982)
Interior wall, 25 mm cavity, interior finish, air film	0.60
	1.05/(2.80, complete summer 1982)
Windows: Double pane	0.35

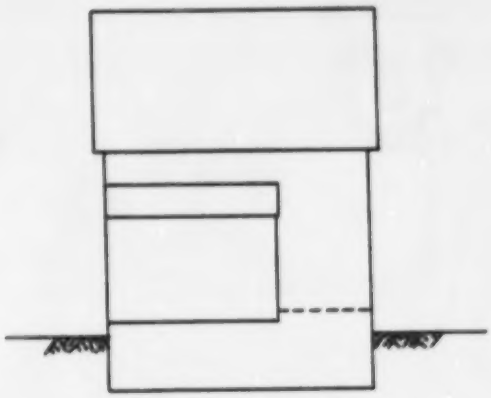
Component: Assembly (approx.)	RSI
Sloped Ceilings:	
Outside air film	0.03
Asphalt shingles	0.08
Roof sheathing	0.17
100 mm cavity: 90% wood shavings (RSI 1.7) with 10% rafters (RSI 0.87)	1.55
Interior finish - lath & plaster	0.12
Inside air film	0.11
	2.06
Attic (vented):	
Attic air film	0.08
200 mm blown cellulose added	0/5.00
100 mm joist space: 10% rafters (RSI 0.87) with 90% wood shavings and zonolite (RSI 1.65)	1.51
Interior finish - lath & plaster	0.12
Inside air film	0.11
	1.82/6.82

Envelope Summary:

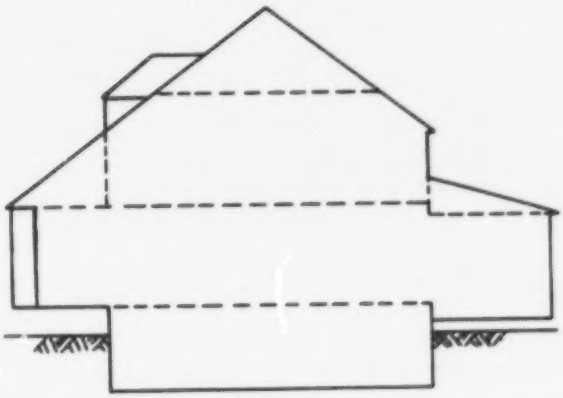
Component	Dimensions (m)	Area (m^2)	RSI
Basement floor:	7.9 x 6.3	49.8	4.4
Basement walls:	28.3 x 2.1	59.4	0.8
Main floor walls:	38.5 x 2.8	107.8	1.12/2.87
- less doors	2 @ 1.75 m^2	3.5	0.7
- less windows	1 @ 1.5 m^2, 4 @ 1 m^2	5.5	0.35
Main floor: front attic	2.1 x 3.5 + 1.5 x 2.7	11.4	1.58/6.58
back attic	4.1 x 2.8	11.5	1.58/6.58
Main floor: front exposed floor	2.1 x 3.5 + 1.5 x 2.7	11.4	1.58
back exposed floor	4.1 x 2.8	11.5	0.86
Second floor walls:	2(7.8 x 2.4 -1) + 6.2 x 1.8	46.6	1.12/(2.87, summer 1982)
knee wall	6.2 x 1.8	11.2	1.05/(2.80, summer 1982)
- less windows	1 @ 1.5 m^2, 3 @ 0.5 m^2	3.0	0.35
Second floor sloped ceiling:	2(6.2 x 1.4)	17.4	2.06
Attic:	6.2 x 5.8	36.0	1.82/6.82



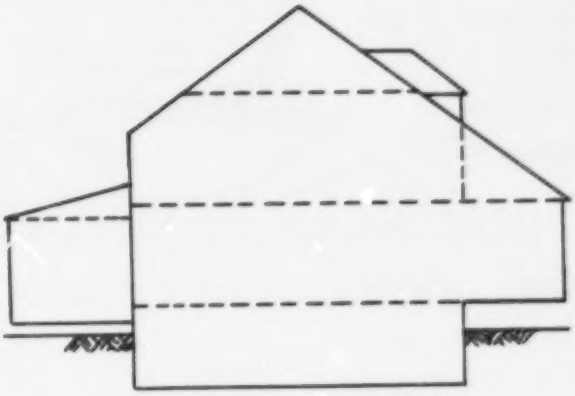
(a)SOUTHWEST SIDE VIEW



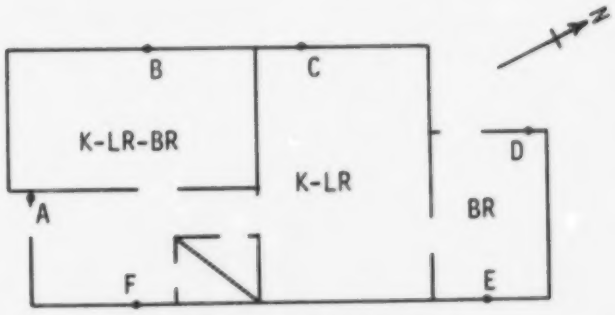
(b)NORTHEAST SIDE VIEW



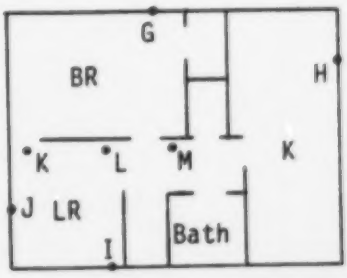
(c)SOUTHEAST SIDE VIEW



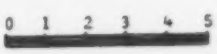
(d)NORTHWEST SIDE VIEW



(e)FIRST FLOOR PLAN VIEW



(f)SECOND FLOOR PLAN VIEW



Scale in m

BUILDING SCHEMATICS

FIGURE A.1

A.3 Test Results

"Before" test	February 25, 1982, 09:00 to 13:30 hrs. Conditions: clear, light winds, average temp. -8°C
Retrofit	March 5 to 10, 1982: Re-insulation of Front, Central, & Rear Attics, & Main Floor Walls
"After" test	March 17, 1982, 09:00 to 13:30 hrs. Conditions: cloudy, snow flurries, average temp. -2°C

Table A.1 Steady-State Furnace Combustion Efficiency

Test	Flue-gas CO_2(%)	Temperature (°C)*	Efficiency(%)
Before	5.25	341	65
After	6.5	338	70

* Conversion from field data recorded to nearest 5°F.

Table A.2 Neutral Pressure Plane Location

Test	Furnace	Location of Neutral Pressure Plane
Before	off	Infiltration below second floor ceiling, exfiltration through attic hatch: NPP at second floor ceiling.
	on	Same as above.
After	off	Infiltration below second floor ceiling, both infiltration and exfiltration at attic hatch: NPP at attic hatch level (200 mm above second floor ceiling).
	on	Infiltration below second floor ceiling, exfiltration at attic hatch: NPP at second floor ceiling.

Table A.3 Occasional Interior Air Temperature & Relative Humidity Measurements

Time	Temp.* (°C)	R.H.* (%)	Dry Bulb** (°C)	Wet Bulb** (°C)	R.H. (%)
02.19.05:50***	26.1	40			
02.20.06:00	26.1	42			
02.22.20:00			22.2	11.7	26
02.23.06:00	23.9	38			
02.24.06:00	22.2	37			
02.25.09:15	19.4	40	19.4	10.6	31
02.25.12:30			19.4(20.6)****	11.1(12.2)	35(36)
02.26.06:00	21.7	38			
02.27.08:30	22.2	36			
02.28.10:00	26.7	39			
03.03.09:30	26.7	36			
03.04.09:30	25.6	35			
03.05.10:00	21.1	35			
03.05.11:00			23.9	12.2	23
RETROFIT					
03.11.08:30	17.8	42			
03.12.08:30	15.6	46			
03.13.09:00	22.8	43			
03.14.09:00	16.7	43			
03.15.09:00	18.3	46			
03.16.08:15	17.2	52			
03.17.08:30	18.9	52			
03.17.09:00			20.0(19.4)	13.9(12.8)	52(47)

* Recorded by homeowner, central location, main floor.
** Recorded by project team, central location, main floor.
*** February 19, 05:50 hrs.
**** Second Floor.

Table A.4 Surface & Air Temperatures On Interior Of Envelope (°C)

Test	Location	W1*	W2	W3	A1	C1	C2	C3
	A	16.7	17.2	17.2	17.2			
	B	14.4	14.4	14.4	18.3			
	C	22.2	20.0	19.4	20.0			
	D	19.4	17.8	16.7	17.2			
	E	16.7	16.7	15.0	17.8			
Before	F	17.2	17.2	16.7	17.8			
02.25.12:30	G	18.3	16.7	16.7	18.3			
	H		17.8		18.3			
	I	16.7	16.7	16.7	17.2			
	J				17.8			
	K					18.3		
	L						19.4	
	M							20.0
	A	18.3	17.2	17.2	17.2			
	B	18.9	18.3	17.8	17.8			
	C	20.0	19.4	18.9	18.3			
	D	18.9	17.2	17.8	17.2			
	E	18.9	18.9	16.1	17.2			
After	F	17.2	17.2	17.8	17.2			
03.17.09:30	G	18.3	17.8	16.7	17.2			
	H		17.8		17.2			
	I	17.2	16.7	17.2	16.7			
	J	18.3	17.2	17.2	17.2			
	K					18.3		
	L						18.3	
	M							18.3

* W1: wall surface, 300 mm below ceiling.
W2: wall surface, 1.5 m above floor.
W3: wall surface, 300 mm above floor.
A1: air within 300 mm of wall, 1.5 m above floor.
C1: ceiling surface, 300 mm from exterior wall.
C2: ceiling surface, halfway to centre of ceiling.
C3: ceiling surface, near centre of ceiling.

** Locations indicated in Figure A.1 (e,f).

Table A.5 Air Infiltration Test Results

Test	Before	After
Airtightness testing unit	Type A	Type A
Location	South door	South door
Temperature (°C)	-10	-4
Wind (km/h)	SW3	N6
Conditions	clear	cloudy, snow
House volume (m^3)	406	406
Envelope above grade (m^2)	282	282
Procedure	CGSB 149-GP-10M Third Draft	CGSB 149-GP-10M Third Draft
Deviations	dryer vent sealed, single outdoor pressure tap	dryer vent sealed, single outdoor pressure tap
Results: $Q = C(\Delta p)^n$		
$C(l/s\text{-}Pa^n)$	92.6	95.6
n	0.659	0.537
Correlation coefficient r	0.994	0.996
$ELA_{10}(m^2)$	0.179	0.138 (22.9% reduction)
(cm^2/m^2 of envelope)	6.33	4.88
AC/hr_{10}	3.74	2.91
AC/hr_{50}	10.81	6.92

Raw Data:

Pressures (Pa) House	Nozzle	Air Flow (l/s)	Pressures (Pa) House	Nozzle	Air Flow (l/s)
6	460	310	9	460	310
8	620	360	12	620	360
10	800	409	15	760	399
12	1090	477	17	1000	457
14	1240	508	20	1070	472
16	1700	595	25	1470	553
18	1910	630	30	1640	584
			36	2020	648

Table A.6 Furnace Cycling Time

Period Starting	Duration (h)	Degree-Days*	Wind** (km/h)	No. of Cycles Total	No. of Cycles /D-D	Burn Time (s)	Burn Time (s/D-D)
BEFORE							
02.22.20:00	10	14.2	18.7	12	0.85	12950	915
02.23.06:00	24	30.9	15.7	45	1.46	27800	901
02.24.06:00	24	30.0	10.3	48	1.60	29680	989
02.26.06:00	26.5	38.7	20.0	47	1.21	35620	920
02.27.08:30	25.5	27.0	24.2	43	1.59	28880	1071
02.28.10:00	24	29.6	24.3	39	1.32	24510	829
03.01.10:00	22	32.1	24.1	30	0.93	26260	817
03.02.08:00	25.5	39.9	10.7	58	1.45	36770	922
03.03.09:30	24	30.3	15.3	46	1.52	29610	978
03.04.09:30	24.5	33.3	21.0	41	1.23	27880	836
TOTAL	230	305.9	18.4	409	1.34	279960	915
AFTER							
03.10.10:00	22.5	27.5	17.8	42	1.53	16330	594
03.11.08:30	24	21.3	44.0	32	1.50	10660	501
03.12.08:30	24.5	23.9	49.7	33	1.38	15310	641
03.13.09:00	24	24.5	24.8	22	0.90	8500	347
03.14.09:00	24	16.6	32.2	33	1.99	15710	949
03.15.09:00	23.25	15.7	18.2	29	1.84	7520	478
03.16.08:15	24.25	17.0	19.6	14	0.82	7190	422
TOTAL	166.5	146.5	29.7	205	1.40	81220	554
Percent Change					+4.4		-39.4

* Degree-Days (D-D) calculated from +18°C base using unofficial hourly temperatures for Winnipeg International Airport.

** Average windspeed in period, based on unofficial hourly windspeeds for Winnipeg International Airport.

Table A.7 Decay Heat Loss

Test	Before	After
Start	-	-
Finish	-	-

Note: Manipulation of interior temperatures not attempted during evening and nighttime hours at request of homeowner.

A.4 Energy-Use Records

Table A.8 Monthly Natural Gas Consumption

Utility: Greater Winnipeg Gas Company
Residence: 261 Lansdowne Avenue

Period	Consumption (m^3)*			
	1980	1981	1982	1983
January	997	1172	1031	
February	864	863	1175	
March	1209	719	1068	
April	643	515		
May	306	388		
June	156	244		
July	116	116		
August	57	76		
September	116	116		
October	190	122		
November	504	351		
December	578	521		
Total	5734	5224	3273	
Cost	$601.77	$667.70	$404.89	

* Conversion from gas company data recorded to nearest one hundred cubic feet. Columns may not add up due to rounding.

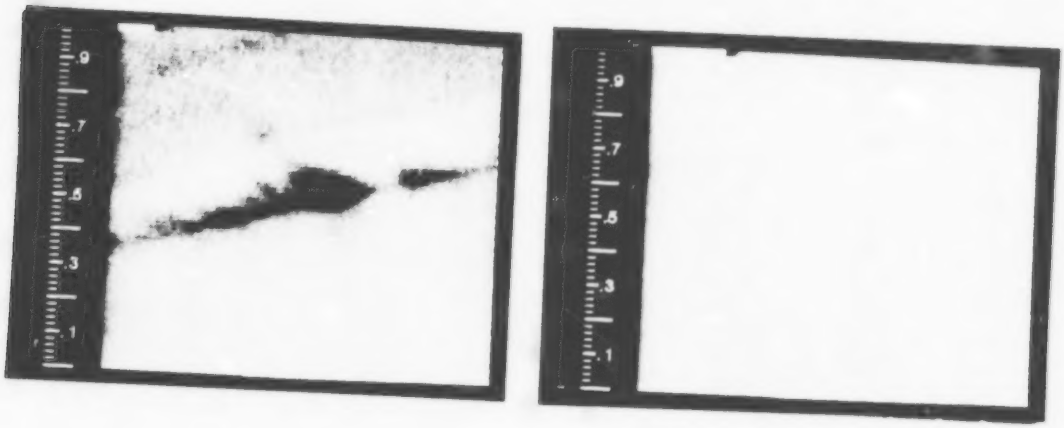
Table A.9 Monthly Electricity Consumption

Utility: Winnipeg Hydro
Residence: 261 Lansdowne Avenue

Period	Consumption (kWh)			
	1980	1981	1982	1983
Jan 1 - Feb 1	889	755	909	
Feb 1 - Mar 1	885	888	641	
Mar 1 - Apr 1	765	642		
Apr 1 - May 1	485	600		
May 1 - Jun 1	490	560		
Jun 1 - Jul 1	414	472		
Jul 1 - Aug 1	462	487		
Aug 1 - Sep 1	404	442		
Sep 1 - Oct 1	418	416		
Oct 1 - Nov 1	502	462		
Nov 1 - Dec 1	665	591		
Dec 1 - Jan 1	1102	694		
Total	7481	7009	1550	

A.5 Thermography

The following photographs are selected from the results of thermographic scans of the interior of the building envelope and are representative of the major problems in the house.



(a) (b)

FIGURE A.2 Effect of Attic Re-insulation on Air Leakage at Second-Floor Wall-Ceiling Joint (wall is uninsulated): (a) Before; (b) After.

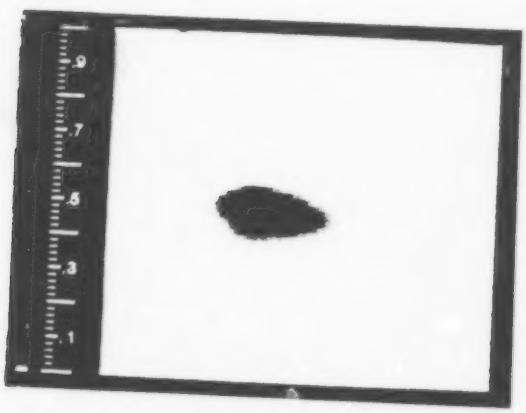
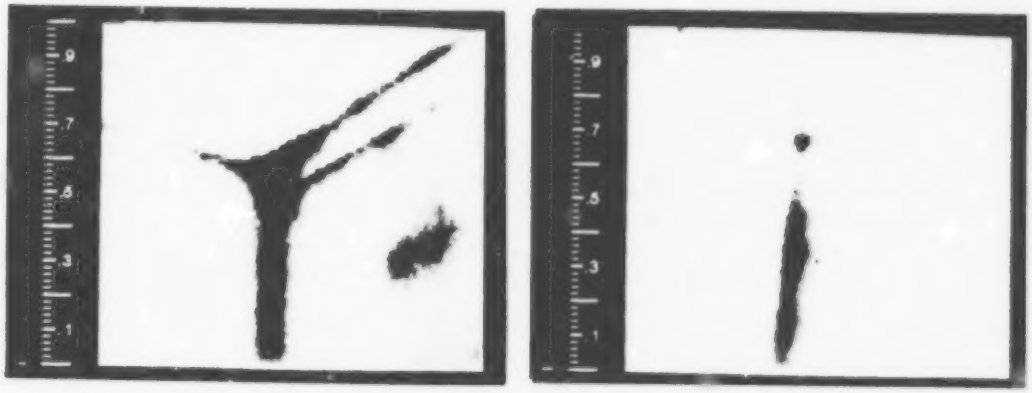


FIGURE A.3 Remains of Old Plumbing Stack, Second-floor Ceiling.



(a) (b)

FIGURE A.4 Effect of Blown-in Insulation on Air Infiltration to the Interior Wall System Through Poorly Sealed Joint at Junction of Rear Addition and Main Building: (a) Before; (b) After.

B.1 General Information

Identification

Address:	107 Newman Avenue West, Winnipeg, Manitoba R2C 2G8

Residence Description

Type of Home:	Single, detached
Year of Construction:	1913
No. of Storeys:	One and one-half
Wall Construction:	Masonry (main floor) & wood frames (second floor)
Type of Foundation:	Basement
No. of Residents:	2

Thermostat

Setting:	Day: 20.6°C* Evening: 20.6°C Night: 17.8°C (Manual)
Test:	Measured interior temp.: 21.1°C Cut-in: 18.9°C

Note: Only kitchen heated regularly; all other ducts normally closed.

Domestic Hot Water

Type of System:	Natural gas
Tank:	Capacity: 114 l Insulation: 25 mm
Measured Temp.:	63.9°C
Daily Use:	General: 20 l/person Washer: 15 l/person Baths: 2 per week

Space Heating

Type of System:	Natural gas forced air
Furnace:	Janitrol FES 120-45 (25V AC controls)
Age:	20 years (estimated)
Ratec Specifications:	Input: 35.1 kW** Output: 28.1 kW**
Fan Operation:	Noncontinuous Cut-in: 82.2°C Cut-out: 29.4°C
Chimney:	Masonry, central

Miscellaneous

Basement:	Temperature: 14 - 15°C Humidity: 48 to 56%
Dryer Venting:	No dryer
Winter Humidifier Use:	Regular
Current Problems:	Only kitchen heated, other rooms cool (13 - 16°C). Infiltration to upper subfloor from outside.

* Unless otherwise indicated all temperatures are conversions from field data recorded to nearest degree Fahrenheit. No further accuracy is implied.

** Conversion from nameplate specification in Btu/hr.

B.2 Building Description

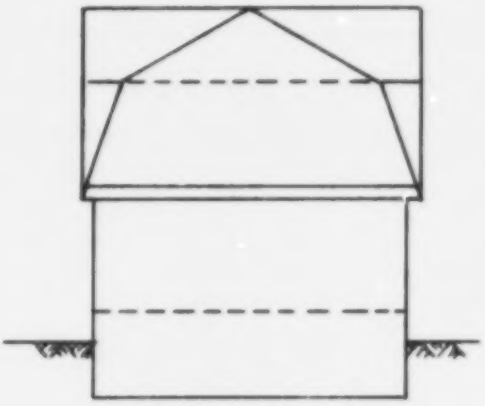
Component: Assembly (approx.)		RSI[1] Before/After
Basement:		
Floors:	Poured concrete	4.4
Walls:	300 mm stone with 50 mm rigid expanded polystyrene, full height (0.8 m above grade, 1.3 m below)	2.1
Main Floor:		
Walls:	Outside air film	0.03
	100 mm clay brick	0.07
	100 mm air cavity	0.16
	100 mm clay brick	0.07
	60 mm wall cavity: 15% structural softwood (RSI 0.52) with 85% air (RSI 0.18) or blown cellulose (RSI 1.5)	0.20/1.17
	Lath & plaster	0.12
	Drywall	0.08
	Interior air film	0.12
		0.85/1.82
Doors:	Inner door with aluminum storm outdoor door	0.7
Windows:	Double pane	0.35
Second Floor Walls:		
	Outside air film	0.03
	Wooden shingles or siding	0.17
	Wooden sheathing	0.17
	100 mm wall cavity: 15% structural softwood (RSI 0.87) with air (RSI 0.18) or zonolite (RSI 1.6)	0.20/(1.42 1 wall 1981 3 walls 1982)
	Lath & plaster	0.12
	Drywall	0.08
	Interior air film	0.12
		0.89/(2.11)

[1] Tables 3.2 and 12.1, Handbook on: Insulating Homes for Energy Conservation, Canadian General Standards Board CGSB 51-GP-42MP, Ottawa, July 1980.

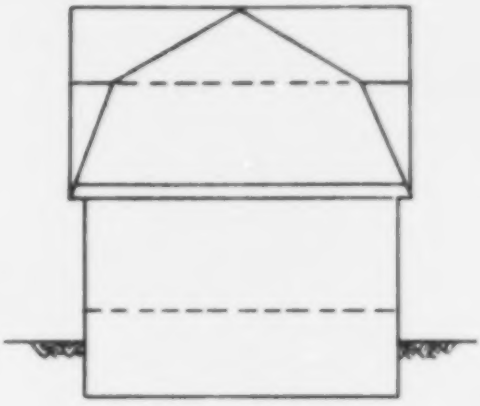
Component: Assembly (approx.)		RSI
Sloped Walls:		
Outside air film		0.03
Asphalt shingles		0.08
Roof sheathing		0.14
100 mm rafter space:	10% softwood rafters (RSI 0.87) with 90% vermiculite (RSI 1.6)	1.48
		0.12
Lath & plaster		0.12
Interior air film		1.97
Windows: Double pane		0.35
Attic (vented):		
Attic air film		0.08
350 mm blown fibreglass		5.25 (early '81)
100 mm joist space:	10% wooden joists (RSI 0.67) with 90% vermiculite (RSI 1.6)	1.48
		0.12
Lath & plaster		0.08
Drywall		0.11
Inside air film		7.12

Envelope Summary:

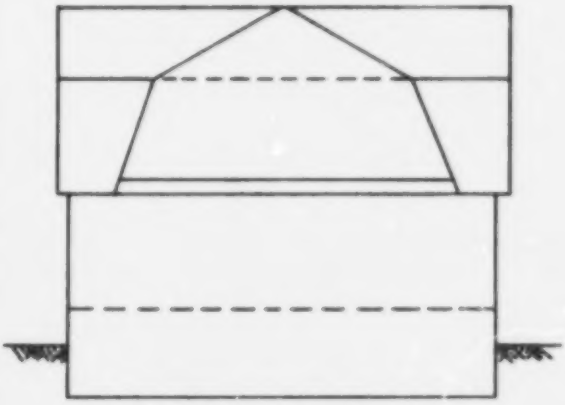
Component	Dimensions (m)	Area (m^2)	RSI
Basement floor:	9.8 x 6.8	66.6	4.4
walls	33.2 x 2.1	69.7	2.1
Main floor walls:	33.2 x 2.7	89.6	0.85/1.82
- less doors	2 @ 1.75 m^2	3.5	0.7
- less windows	1 @ 1.5 m^2, 5 @ 1.0 m^2, 4 @ 0.5 m^2	8.5	0.35
Second floor front wall:	(7.4 + 4.9) + 2 x 2.7	16.6	2.11(1981)
- sides & back	3 @ (7.4 + 4.9) + 2 x 2.7	49.8	0.89/(2.11 in '82)
- less windows	7 @ 1 m^2	7.0	0.35
Second floor sloped walls:	4 corners @ (6.7 + 2.1)	35.2	1.97
Second floor attic:	9.8 x 4.9 +2 (4.9 x 1.3)	60.8	7.12(1981)



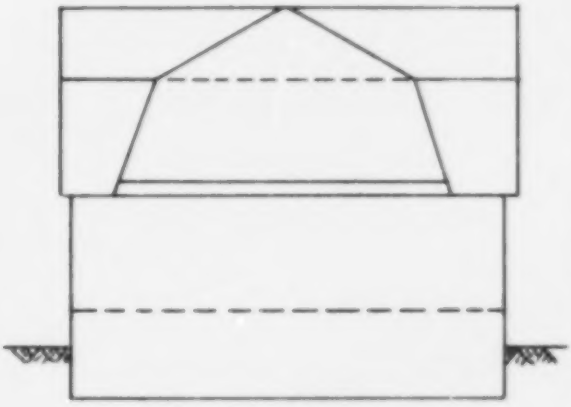
(a)SOUTH SIDE VIEW



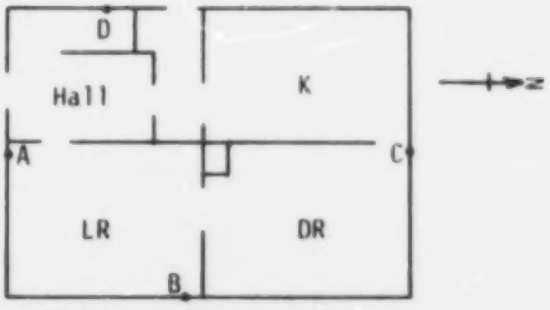
(b)NORTH SIDE VIEW



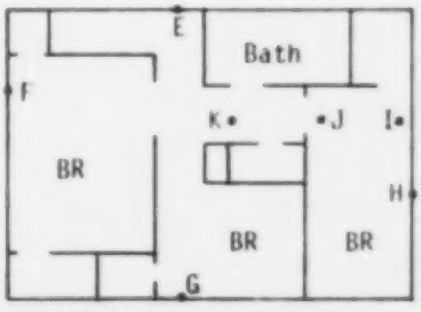
(c)EAST SIDE VIEW



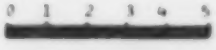
(d)WEST SIDE VIEW



(e)FIRST FLOOR PLAN VIEW



(f)SECOND FLOOR PLAN VIEW



Scale in m

BUILDING SCHEMATICS

FIGURE B.1

B.3 Test Results

"Before" test	March 17, 1982, 14:30 to 19:30 hrs. Conditions: overcast, -4°C, N6 km/h
Retrofit	March 18 to 19, 1982: Re-insulation of Main Floor Walls
"After" test	March 30, 1982, 13:00 to 16:30 hrs. Conditions: overcast, rain, +6°C, NE7 km/h

Table B.1 Steady-State Furnace Combustion Efficiency

Test	Flue-gas CO_2(%)	Temperature (°C)*	Efficiency(%)
Before	6.25	288	72.5
After	6.5	293	72.5

* Conversion from field data recorded to nearest 5°F.

Table B.2 Neutral Pressure Plane Location

Test	Furnace	Location of Neutral Pressure Plane (NPP)
Before	off	At mid-height of second floor windows.
	on	At mid-height of second floor windows, unchanged from furnace off.
After	off	All infiltration below second floor ceiling, infiltration and exfiltration at attic hatch with infiltration dominating: NPP just above attic hatch.
	on	All infiltration including at attic hatch, air inflow at attic hatch is less intense than during periods of infiltration while furnace is off: NPP above attic hatch.

Table B.3 Occasional Interior Air Temperature & Relative Humidity Measurements

Time	Temp.* (°C)	R.H.* (%)	Dry Bulb** (°C)	Wet Bulb** (°C)	R.H. (%)
03.12.20:10	24	41	22.2	13.9	40
03.13.00:00	24	39			
03.13.07:00	16	39			
03.13.18:30	22	45			
03.13.23:30	22	44			
03.14.11:30	16	39			
03.14.23:30	23	41			
03.15.08:30	21	41			
03.15.15:30	23	50			
03.15.20:30	24	56			
03.16.08:30	13	54			
03.16.20:30	15	51			
03.17.08:00	16	51			
03.17.14:00			15.0(15.0)****	9.4(9.4)	48(48)
03.17.20:00	20	50			
03.18.08:00	17	45			
RETROFIT					
03.20.09:00	19	45			
03.20.21:30	23	55			
03.21.08:30	20	49			
03.22.00:30	19	49			
03.22.09:00	19	48			
03.22.23:00	25	53			
03.23.08:30	20	50			
03.23.21:00	24	55			
03.24.08:30	20	45			
03.24.20:30	23	50			
03.25.08:30	21	42			
03.25.20:30	22	60			
03.26.08:30	21	50			
03.27.09:30	19	39			
03.27.20:30	17	51			
03.28.06:30	17	41			
03.28.23:00	18	48			
03.29.09:00	19	45			
03.29.21:00	15	48			
03.30.09:00	16	52			
03.30.13:00			13.3(13.9)	8.3(8.9)	50(51)
03.30.16:00			20	12.8	43

* Recorded by homeowner in °C: in heated kitchen (03.12 to 03.26) in unheated area of main floor (03.27 to 03.30).

** Recorded by project team: in heated kitchen (03.12, 03.30.16:00) in unheated area of main floor (03.17, 03.30.13:00)

*** March 12, 20.10 hrs.

**** Second floor

Table B.4 Surface & Air Temperatures On Interior Of Envelope (°C)

Test	Location	W1*	W2	W3	A1	C1	C2	C3
	A**	13.3	12.8	12.2	12.2			
	B	12.8	12.2	12.8	10.6			
	C	13.9	13.3	13.9	13.9			
	D	12.8	11.7		11.7			
Before	E		12.8	12.8	12.8			
03.17.15:00	F	14.4	14.4	14.4	13.3			
	G	13.9	13.9	13.3	13.9			
	H	12.8	12.2	12.2	12.8			
	I					14.4		
	J						13.9	
	K							15.0
	A	17.8	17.8	14.4	19.4			
	B	13.3	13.3	13.3	15.6			
	C	15.6	15.6	15.0	15.6			
	D	14.4	13.3		15.0			
After	E		13.3	11.7	13.9			
03.30.13:00	F	12.2	12.2	11.7	12.2			
	G	12.8	11.7	11.7	12.8			
	H	12.8	12.2	12.2	13.3			
	I					13.3		
	J						13.9	
	K							13.9

* W1: wall surface, 300 mm below ceiling.
W2: wall surface, 1.5 m above floor.
W3: wall surface, 300 mm above floor.
A1: air within 300 mm of wall, 1.5 m above floor.
C1: ceiling surface, 300 mm from exterior wall.
C2: ceiling surface, halfway to centre of ceiling.
C3: ceiling surface, near centre of ceiling.

** Locations indicated in Figure B.1 (e,f).

Table B.5 Air Infiltration Test Results

Test	Before	After
Airtightness testing unit	Type A	Type A
Location	West door	West door
Temperature (°C)	-4	+6
Wind (km/h)	N6, gusting	NE7, gusting
Conditions	clear	cloudy
House volume (m^3)	505	505
Envelope above grade (m^2)	279	279
Procedure	CGSB 149-GP-10M Third Draft	CGSB 149-GP-10M Third Draft
Deviations	single outdoor pressure tap	single outdoor pressure tap
Results: $Q = C(\Delta p)^n$		
$C(l/s\text{-}Pa^n)$	98.7	44.5
n	0.584	0.764
Correlation coefficient r	0.987	0.999
$ELA_{10}(m^2)$	0.158	0.106 (32.9% reduction)
(cm^2/m^2 of envelope)	5.68	3.81
AC/hr_{10}	2.70	1.84
AC/hr_{50}	6.91	6.31

Raw Data:

Pressures (Pa) House	Nozzle	Air Flow (l/s)	Pressures (Pa) House	Nozzle	Air Flow (l/s)
10	750	396	10	310	255
14	930	441	12	430	300
16	1110	481	15	610	357
18	1340	528	16	650	369
20	1560	570	20	910	436
22	1610	614	24	1220	504
24	1930	634	28	1610	579
26	2160	670	32	1840	619
			36	2280	688

Table B.6 Furnace Cycling Time

Period Starting	Duration (h)	Degree-Days*	Wind** (km/h)	No. of Cycles Total	No. of Cycles /D-D	Burn Time (s)	Burn Time (s/D-D)
BEFORE							
03.12.20:40N***	10.33	9.6	64.8	14	1.46	6580	684
03.13.07:00	16.5	15.5	38.7	28	1.80	16620	1069
03.13.23:30N	9.0	10.4	8.0	17	1.63	7530	723
03.14.08:30	15.0	10.8	29.6	19	1.77	8660	806
03.14.23:30N	9.0	6.0	35.4	16	2.68	5860	983
03.15.08:30	12.0	7.7	27.5	11	1.43	5370	696
03.15.20:30N	12.0	8.5	9.8	13	1.52	5180	607
03.16.08:30	12.0	8.1	17.2	11	1.36	5290	655
03.16.20:30N	11.5	8.4	22.0	13	1.56	5440	651
03.17.20:00N	12.0	14.3	35.2	18	1.26	11220	786
TOTAL	119.3	99.2	29.1	160	1.61	77750	783
"N" Only	63.8	57.2	29.0	91	1.59	41810	731
AFTER							
03.20.21:30N	11.0	11.0	13.7	16	1.46	7260	662
03.21.08:30	16.0	11.6	15.0	10	0.86	4660	401
03.22.00:30N	8.5	8.4	3.5	13	1.56	4850	581
03.22.09:00	14.0	10.5	20.7	14	1.33	6740	639
03.22.23:00N	9.5	7.6	12.6	8	1 05	3490	459
03.23.08:30	12.5	9.0	15.0	11	1.22	5700	631
03.23.21:00N	11.5	10.7	33.1	16	1.50	6690	627
03.24.08:30	12.0	11.6	36.3	13	1.12	8360	719
03.24.20:30N	12.0	14.4	16.8	20	1.39	9520	662
03.25.08:30	12.0	12.4	13.5	14	1.13	6860	554
03.25.20:30N	12.0	14.3	13.5	16	1.12	7920	556
03.26.08:30	25.0	25.1	15.8	41	1.63	16540	659
03.27.09:30	11.0	8.2	45.9	9	1.10	4560	555
03.28.23:00	22.0	13.1	28.0	8	0.61	3330	255
03.29.21:00N	12.0	7.0	25.9	7	1.00	3130	447
TOTAL	201.0	174.8	20.8	216	1.24	99610	570
Percent Change					-23.0		-27.2
"N" Only	76.5	73.21	17.7	96	1.31	42860	585
Percent Change					-17.6		-20.0

* Degree-Days (D-D) calculated from +18°C base using unofficial hourly temperatures for Winnipeg International Airport.

** Average windspeed in period, based on unofficial hourly windspeeds for Winnipeg International Airport.

*** Symbol "N" denotes overnight measurement period (occupant activity and solar effects minimal).

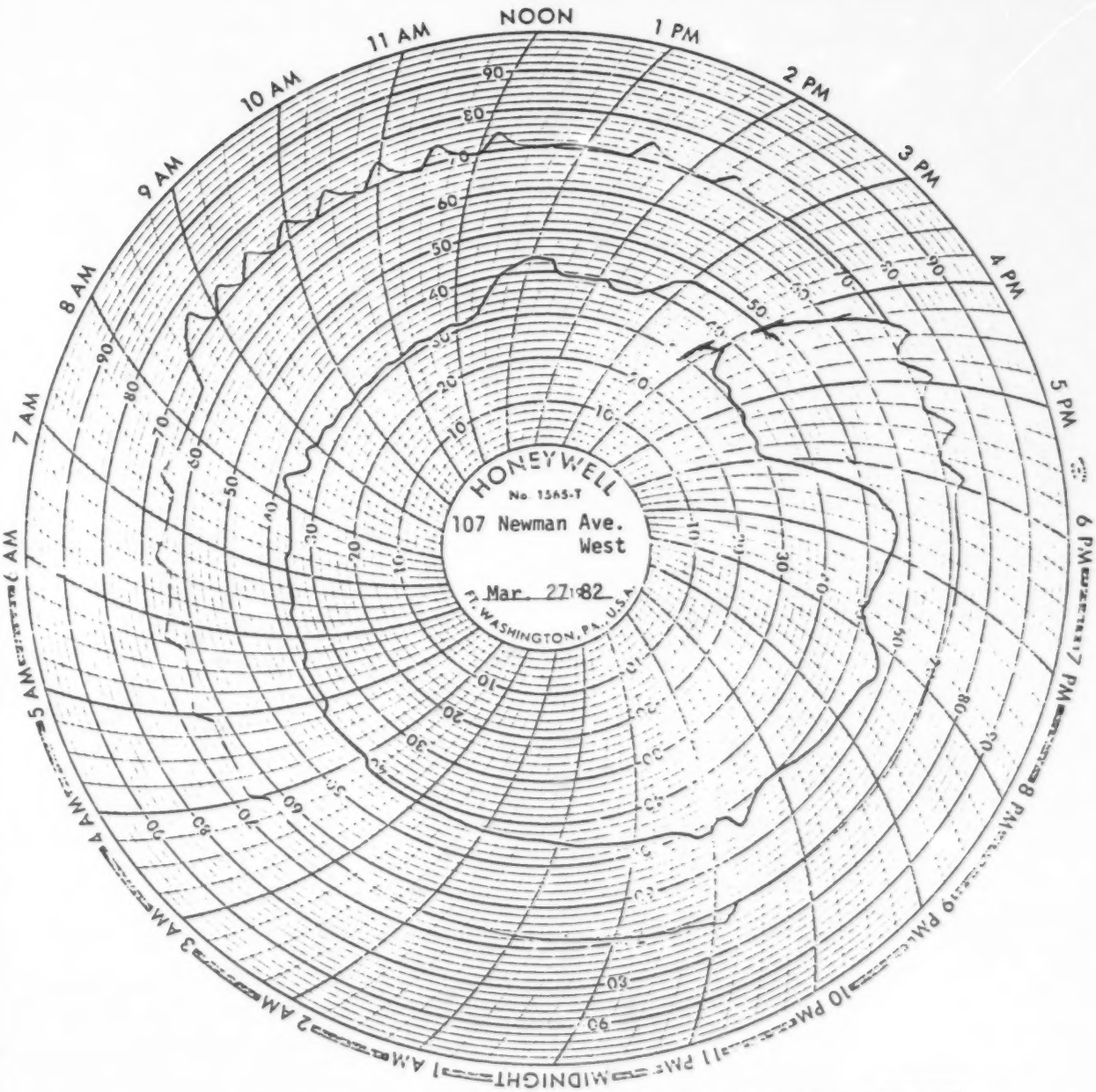
Table B.7 Decay Heat Loss

Test	Before	After
Start	-	82.03.27.23:30
Finish	-	82.03.28.04:00
Occupants		Present
Furnace Fan		Off
Exterior Air Temperature (°C)*:		
Start		-0.3
Finish		+0.4
Mean - during test		+0.1
Mean - preceding 24 h		+3.1
Windspeed Indicator (km/h)**:		
Start		42
Finish		26
Mean - during test		34.2
Mean - preceding 24 h		35.3
Relative cooling rate (h^{-1})***:		
Hour: 1		0.0696
2		0.0513
3		0.0360
4		0.0316

Note: Heat normally directed to one room (kitchen) in the house only; recorder located in this room for test.

* Based on unofficial hourly temperatures for Winnipeg International Airport.
** Based on unofficial hourly windspeeds for Winnipeg International Airport: to be used for comparison only because actual windspeeds near the building are significantly lower.
*** Interior air-temperature drop over one hour divided by average interior/exterior air-temperature difference over the same hour.

FIGURE B.2 DECAY HEAT LOSS TEST - AFTER RETROFIT



Note: Light trace represents indoor air temperature; dark trace represents indoor relative humidity (not calibrated: use as indicator of trends only.

B.4 Energy-Use Records

Table B.8 Monthly Natural Gas Consumption

Utility: Greater Winnipeg Gas Company
Residence: 107 Newman Avenue West

Period	Consumption (m^3)*			
	1980	1981	1982	1983
January	1113	1254	1042	
February	643	544	810	
March	946	524	445	
April	201	337		
May	170	252		
June	79	93		
July	85	82		
August	105	82		
September	144	139		
October	266	320		
November	362	249		
December	716	784		
Total	4831	4661	2296	
Cost	$517.16	$608.28	$322.67	

* Conversion from gas company data recorded to nearest one hundred cubic feet. Columns may not add up due to rounding.

Table B.9 Monthly Electricity Consumption

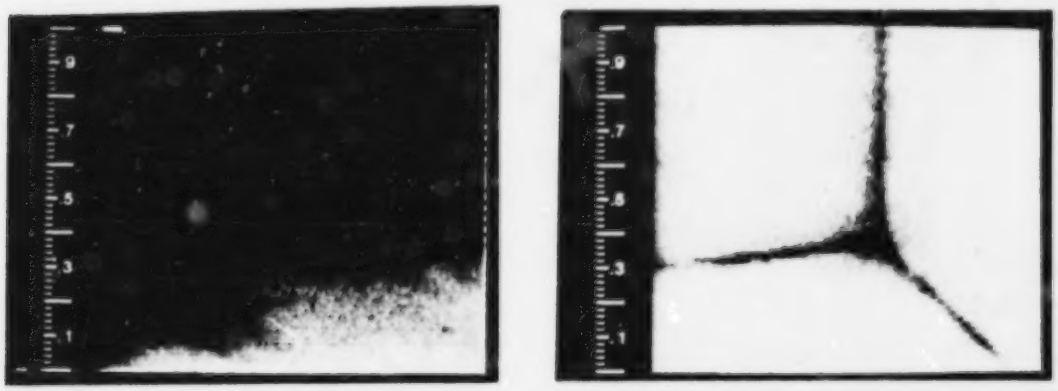
Utility: Manitoba Hydro
Residence: 107 Newman Avenue West

Period	Consumption (kWh)			
	1980	1981	1982	1983
January				
February	1758(64)*	1780(62)	1603(63)	
March				
April	1406(61)	1184(60)		
May				
June	968(52)	968(53)		
July				
August	1358(64)	1318(62)		
September				
October	1121(56)	1167(64)		
November				
December	1225(63)	1191(61)		
Total	7836(360)	7608(362)	1603(63)	

* Number of days between readings.

B.5 Thermography

The following photographs are selected from the results of thermographic scans of the interior of the building envelope and are representative of the major problems in the house.



(a) (b)

FIGURE B.3 Air Leakage at Junction of Two Exterior Walls: (a) Before re-insulation; (b) After re-insulation.

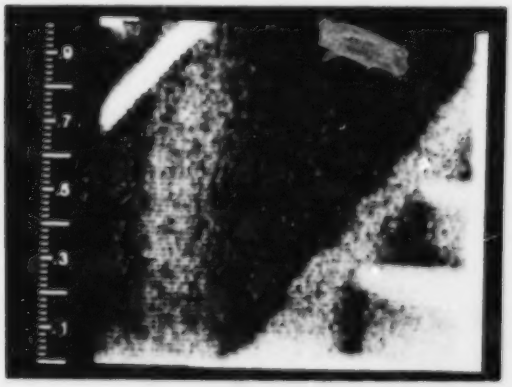
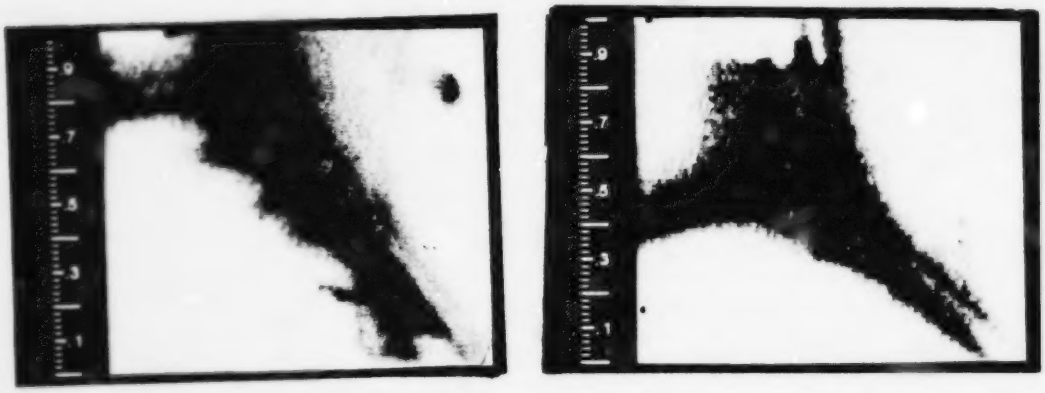


FIGURE B.4 Crack at Junction of Staircase and Exterior Wall (Dark spots on wall are wall-cavity access holes).



(a) (b)

FIGURE B.5 Reduction of Air Leakage above Sill Plate by Re-insulation of Wall Cavities: (a) Before re-insulation (dark spot is wall-cavity access hole); (b) After re-insulation, the air infiltration is localized in corner. Note thermal bridging at the stud.

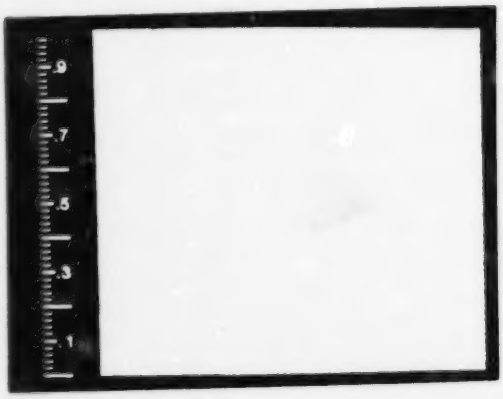


FIGURE B.6 Cold Joist Spaces in Main-Floor Ceiling Which Are Open to Double-Brick Walls at Building Perimeter.

C.1 General Information

Identification	
Address:	353 Chalmers Avenue, Winnipeg, Manitoba R2L 0G3
Residence Description	
Type of Home:	Single, detached
Year of Construction:	1907
No. of Storeys:	One
Wall Construction:	Wood frame
Type of Foundation:	Basement
No. of Residents:	3
Thermostat	
Setting:	Day: 19.4°C* Evening: 19.4°C Night: 19.4°C (Manual)
Test:	Measured interior temp.: 20.0°C Cut-in: 18.9°C
Domestic Hot Water	
Type of System:	Electric
Tank:	Capacity: 182 l Insulation: 25 mm
Measured Temp.:	68.9°C
Daily Use:	General: 45 l/person Washer: 15 l/person
Space Heating	
Type of System:	Natural gas forced air
Furnace:	Bulloch's Ltd. AC-90-GLB (millivolt controls)
Age:	15 years (estimated)
Rated Specifications:	Input: 26.4 kW** Output: 21.4 kW**
Fan Operation:	Noncontinuous Cut-in: 60°C
Chimney:	Masonry, central
Miscellaneous	
Basement:	Temperature: 19.4°C Humidity: 53%
Dryer Venting:	Inside
Winter Humidifier Use:	Regular
Current Problems:	Cold at main floor level (leaky baseboards, doors)

* Unless otherwise indicated, all temperatures are conversions from field data recorded to nearest degree Fahrenheit. No further accuracy is implied.

** Conversion from nameplate specification in Btu/hr.

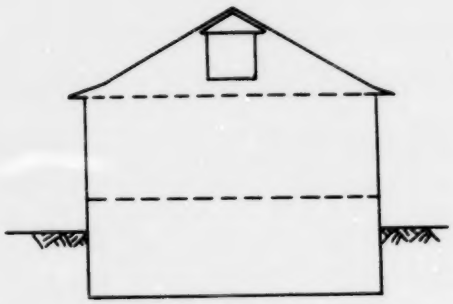
C.2 Building Description

Component: Assembly (approx.)		RSI[1] Before/After
Basement:		
Floors:	Poured concrete	4.4
Walls:	Poured concrete, framed & insulated to full depth with fibreglass batts (RSI 2.1), 0.8 m above grade 1.6 m below	2.9
Main Floor:		
Walls:	Outside air film	0.03
	Stucco	0.03
	Softwood sheathing	0.17
	100 mm wall cavity: 15% structural softwood (RSI 0.87) with 85% air (RSI 0.18) or blown cellulose (RSI 2.5)	0.20/1.95
	Interior finish - drywall	0.08
	Interior air film	0.12
		0.63/2.38
Doors:	Inner door with aluminum storm outdoor door	0.7
Windows:	Double pane	0.35
Attic (vented):		
	Attic air film	0.08
	100 mm joist space: 10% structural softwood (RSI 0.87) with 90% wood shavings (RSI 1.7)	1.55
	Interior finish - drywall	0.08
	Interior air film	0.11
		1.82(to be augmented in future)

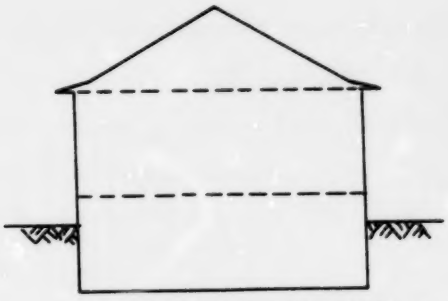
Envelope Summary:

Component	Dimensions (m)	Area (m^2)	RSI
Basement floor:	10.5 x 6.9	72.5	4.4
walls	34.8 x 2.4	83.5	2.9
Main floor walls:	34.8 x 2.4	83.5	0.63/2.38
- less doors	2 @ 1.75 m^2	3.5	0.7
- less windows	1 @ 1.5 m^2, 6 @ 1.0 m^2	6.5	0.35
Main floor attic:	10.5 x 6.9	72.5	1.82(to be augmented in future)

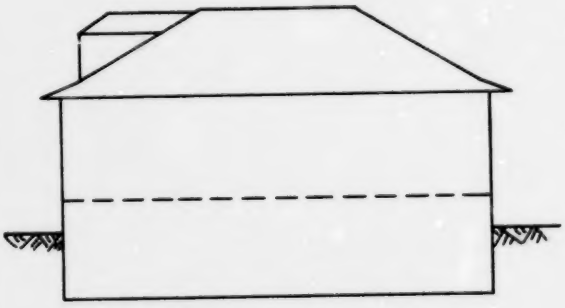
[1] Tables 3.2 and 12.1, Handbook on: Insulating Homes for Energy Conservation, Canadian General Standards Board CGSB 51-GP-42MP, Ottawa, July 1980.



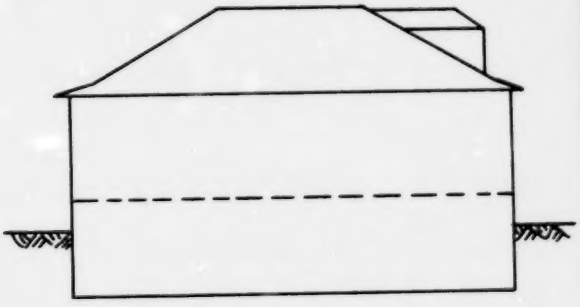
(a)SOUTHWEST SIDE VIEW



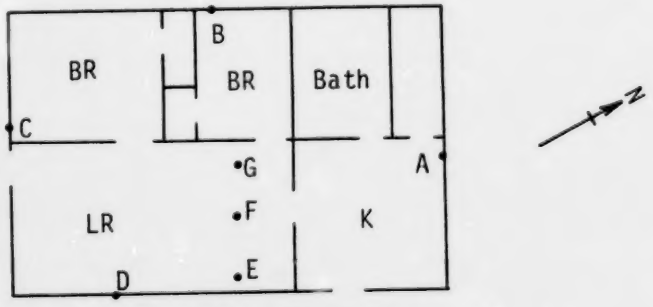
(b)NORTHEAST SIDE VIEW



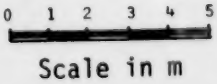
(c)SOUTHEAST SIDE VIEW



(d)NORTHWEST SIDE VIEW



(e)FIRST FLOOR PLAN VIEW



Scale in m

BUILDING SCHEMATICS

FIGURE C.1

C.3 Test Results

"Before" test	March 19, 1982, 8:45 to 12:30 hrs. Conditions: clear, -2°C, E6 km/h
Retrofit	April 6,7, 1982: Re-insulation of walls
"After" test	April 12, 1982, 8:45 to 11:45 hrs. Conditions: cloudy, +4°C, NE3 km/h; cleared at 10:00 hrs. followed by rapid warming to 11°C by 11:45 hrs.

Table C.1 Steady-State Furnace Combustion Efficiency

Test	Flue-gas CO_2(%)	Temperature (°C)*	Efficiency(%)
Before	5.0	316	66.5
After	5.25	316	67

* Conversion from field data recorded to nearest 5°F.

Table C.2 Neutral Pressure Plane Location

Test	Furnace	Location of Neutral Pressure Plane (NPP)
Before	off	Infiltration on all walls except east corner where door experiencing both infiltration & exfiltration (80% infiltration) on approximately 2-minute cycle, exfiltration at attic hatch: NPP at ceiling level.
	on	Walls & door unchanged from furnace-off case, infiltration at attic hatch: NPP above ceiling.
After	off	Infiltration on all walls and ceiling, including attic hatch: NPP above ceiling.
	on	Unchanged from above: NPP above ceiling.

Table C.3 Occasional Interior Air Temperature & Relative Humidity Measurements

Time	Temp.* (°C)	R.H.* (%)	Dry Bulb** (°C)	Wet Bulb** (°C)	R.H. (%)
03.18.19:30***	20.6	57			
03.19.06:35	21.7	49			
03.19.08:45	21.1	52			
03.19.09:00			19.4	12.2	42
03.19.11:45	20.0	48			
03.19.17:20	21.7	50			
03.20.07:00	21.7	48			
03.21.01:05	21.7	50			
03.21.08:00	22.2	48			
03.21.22:30	22.2	50			
03.22.05:30	22.2	50			
03.22.21:00	21.7	55			
03.23.05:30	21.1	52			
03.23.23:00	21.7	55			
03.24.06:15	23.3	51			
03.24.21:25	21.7	53			
03.25.05:30	22.2	50			
03.25.23:00	23.3	50			
03.26.05:30	22.8	48			
03.26.23:30	22.8	52			
03.27.08:00	23.3	50			
03.30.21:30	21.7	55			
03.31.05:30	21.7	53			
03.31.23:00	21.7	52			
04.01.06:00	23.3	50			
04.01.23:00	22.2	50			
04.02.06:00	22.2	49			
04.02.24:00	21.7	48			
04.03.08:00	22.2	46			
04.04.01:30	24.4	43			
04.04.08:30	24.4	44			
04.04.22:00	22.2	45			
04.05.06:00	25.0	44			
04.05.23:00	24.4	47			
04.06.05:30	25.0	46			
RETROFIT					
04.07.23:00	21.7	50			
04.08.06:00	22.2	49			
04.08.23:00	23.3	53			
04.09.08:00	26.1	48			
04.09.22:00	21.1	51			
04.11.22:00	21.7	49			
04.12.06:00	23.3	49			
04.12.09:00			20.0	14.4	55
04.12.21:00	21.1	53			
04.13.23:00	22.2	56			

* Recorded by homeowner, main floor centre.
** Recorded by project team, main floor centre.
*** March 18, 19:30 hrs.

Table C.4 Surface & Air Temperatures On Interior Of Envelope (°C)

Test	Location	W1*	W2	W3	A1	C1	C2	C3
	A**	15.6	15.6	14.4	16.7			
	B	16.7	16.7	15.0	17.2			
	C	15.6	15.0	13.3	16.7			
Before	D	16.1	16.1	15.6	17.2			
03.19.09:00	E					18.9		
	F						20.0	
	G							21.1
	A	18.3	18.9	18.3	18.3			
	B	20.0	20.0	18.9	20.0			
	C	18.9	18.3	18.3	18.3			
After	D	18.9	18.3	18.3	18.3			
04.12.09:00	E					20.6		
	F						21.1	
	G							21.1

* W1: wall surface, 300 mm below ceiling.
W2: wall surface, 1.5 m above floor.
W3: wall surface, 300 mm above floor.
A1: air within 300 mm of wall, 1.5 m above floor.
C1: ceiling surface, 300 mm from exterior wall.
C2: ceiling surface, halfway to centre of ceiling.
C3: ceiling surface, near centre of ceiling.

** Locations indicated in Figure C.1 (e).

Table C.5 Air Infiltration Test Results

Test	Before	After
Airtightness testing unit	Type A	Type A
Location	Southwest door	Southwest door
Temperature (°C)	-2	+7
Wind (km/h)	E6	NE3
Conditions	clear	cloudy; cleared off at time of test
House volume (m^3)	352	352
Envelope above grade (m^2)	184	184
Procedure	CGSB 149-GP-10M Third Draft	CGSB 149-GP-10M Third Draft
Deviations	single outdoor pressure tap	single outdoor pressure tap
Results: $Q = C(\Delta p)^n$		
$C(l/s\text{-}Pa^n)$	42.8	35.3
n	0.683	0.682
Correlation coefficient r	0.998	0.999
$ELA_{10}(m^2)$	0.0862	0.0697 (19.1% reduction)
(cm^2/m^2 of envelope)	4.67	3.79
AC/hr_{10}	2.11	1.74
AC/hr_{50}	6.32	5.21

Raw Data:

Pressures (Pa) House	Nozzle	Air Flow (l/s)	Pressures (Pa) House	Nozzle	Air Flow (l/s)
10	190	200	10	130	166
15	360	275	15	240	225
20	530	333	20	360	275
25	750	396	25	500	324
30	910	436	30	630	363
35	1170	694	35	790	406
40	1350	530	40	930	441
45	1580	574	44	1050	468
51	1760	605	50	1220	504
			55	1410	542
			60	1570	572
			65	1730	600

Note: Wall-cavity access holes not re-stuccoed.

Table C.6 Furnace Cycling Time

Period Starting	Duration (h)	Degree-Days*	Wind** (km/h)	No. of Cycles Total	No. of Cycles /D-D	Burn Time (s)	Burn Time (s/D-D)
BEFORE							
03.20.07:00	18.08	16.9	21.6	20	1.18	11210	662
03.21.01:05N***	6.92	6.8	13.7	13	1.90	7100	1040
03.21.08:00	14.50	10.3	16.5	12	1.16	6950	674
03.21.22:30N	7.0	6.6	2.6	12	1.81	6140	926
03.22.05:30	15.5	12.6	17.6	20	1.59	8700	690
03.22.21:00N	8.5	6.5	13.9	12	1.84	6010	922
03.23.05:30	17.5	13.1	15.5	18	1.38	9520	729
03.23.23:00N	7.25	6.8	33.3	13	1.92	6550	969
03.24.06:15	15.17	15.0	36.4	25	1.67	11610	776
03.24.21:25N	8.08	9.6	17.3	16	1.67	8920	930
03.25.05:30	17.5	18.9	13.7	23	1.22	12030	636
03.25.23:00N	6.5	7.7	14.1	12	1.56	8400	1089
03.30.21.30N	8.0	5.6	39.0	11	1.95	6670	1185
03.31.05:30	17.5	16.4	43.9	20	1.22	11120	679
03.31.23:00N	7.0	7.9	18.4	12	1.52	8390	1059
04.01.06:00	17.0	16.2	22.4	22	1.36	14030	867
04.01.23:00N	7.0	5.9	25.7	12	2.05	6640	1134
04.02.06:00	18.0	18.8	48.4	27	1.44	17460	928
04.02.24:00N	8.0	10.5	52.8	21	1.99	11720	1112
04.03.08:00	17.5	22.6	40.6	33	1.46	20690	917
04.04.01:30N	7.0	10.5	8.7	17	1.62	11460	1091
04.04.08:30	13.5	15.3	11.5	13	0.85	7890	516
04.04.22:00N	8.0	10.2	9.4	14	1.37	11000	1079
04.05.06:00	17.0	19.2	16.5	19	0.99	11240	586
04.05.23:00N	6.5	8.0	5.8	13	1.62	9120	1134
TOTAL	294.5	297.9	23.9	430	1.44	250570	841
"N" Only	95.75	102.7	20.1	178	1.73	108120	1053
AFTER							
04.07.23:00N	7.0	6.2	8.7	10	1.61	5460	879
04.08.06:00	17.0	12.4	21.1	16	1.29	7960	642
04.08.23:00N	9.0	6.8	25.0	10	1.46	5860	858
04.09.08:00	14.0	10.3	26.0	11	1.07	5470	531
04.09.22:00	48.0	38.2	26.6	46	1.20	25200	660
04.11.22:00N	9.0	4.9	24.5	8	1.65	4500	927
04.13.23:00N	7.0	4.3	28.3	8	1.86	4130	963
TOTAL	110.0	83.1	24.4	109	1.31	58580	705
Percent Change					-9.1		-16.2
"N" Only	31.0	22.2	21.9	36	1.62	19950	899
Percent Change					-6.3		-14.6

* Degree-Days (D-D) calculated from +18°C base using unofficial hourly temperatures for Winnipeg International Airport.

** Average windspeed in period, based on unofficial hourly windspeeds for Winnipeg International Airport.

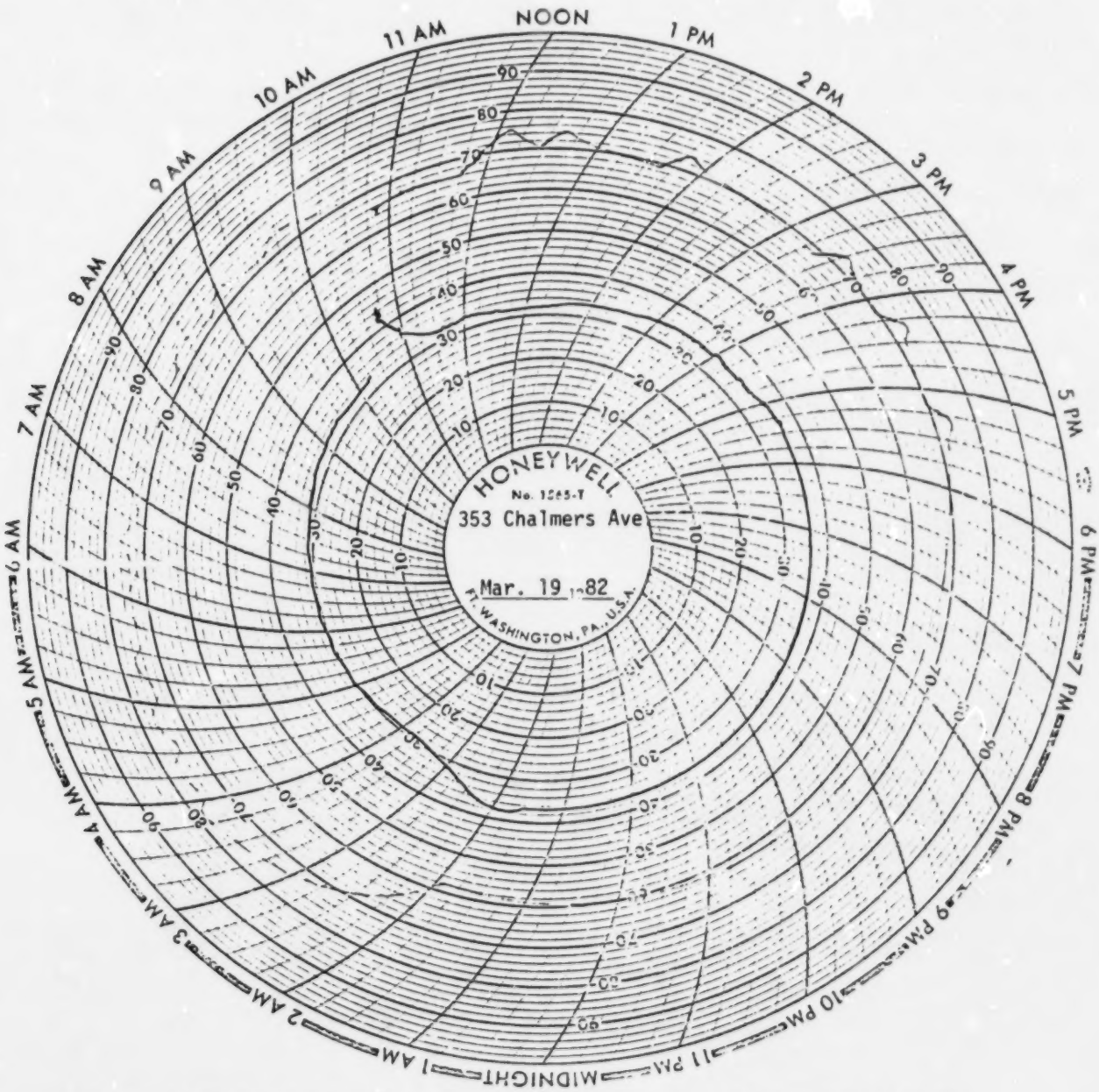
*** Symbol "N" denotes overnight measurement period (occupant activity and solar effects minimal).

Table C.7 Decay Heat Loss

Test	Before	After
Start	82.03.19.17:30	82.04.12.21:00
Finish	82.03.20.02:00	82.04.13.05:45
Occupants	Absent	Present
Furnace Fan	Off	Off
Exterior Air Temperature (°C)*:		
Start	-1.2	+1.5
Finish	-9.0	-2.8
Mean - during test	-6.3	-0.9
Mean - preceding 24 h	-8.3	+5.3
Windspeed Indicator (km/h)**:		
Start	23	20
Finish	17	3
Mean - during test	15.8	12.1
Mean - preceding 24 h	16.8	22.0
Relative cooling rate (h^{-1})***:		
Hour: 1	0.0878	0.0146
2	0.0454	0.0144
3	0.0407	0.0316
4	0.0355	0.0227
5	0.0351	0.0169
6	0.0344	0.0280
7	0.0180	0.0137
8	0.0323	0.0192

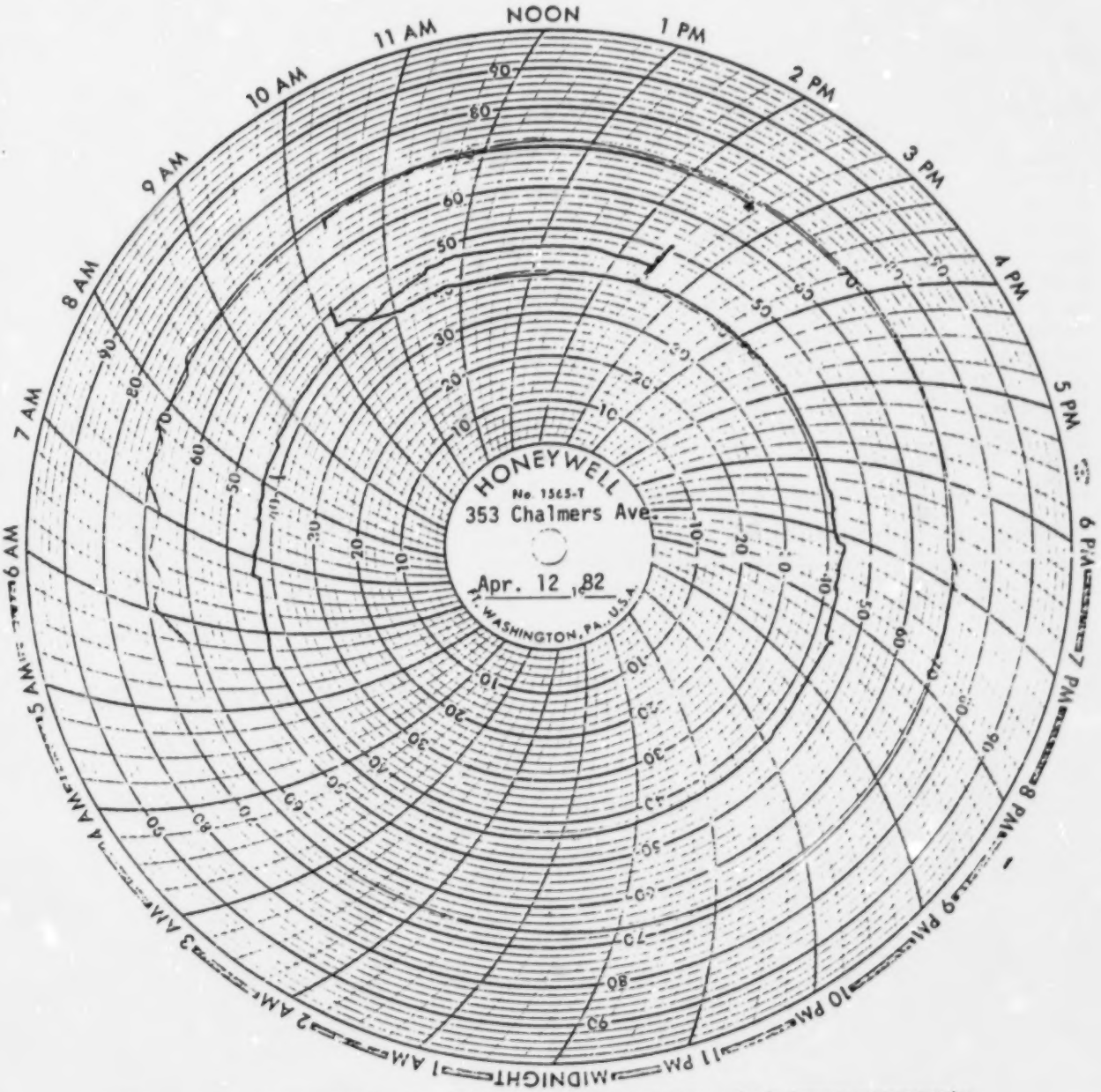
* Based on unofficial hourly temperatures for Winnipeg International Airport.
** Based on unofficial hourly windspeeds for Winnipeg International Airport: to be used for comparison only because actual windspeeds near the building are significantly lower.
*** Interior air-temperature drop over one hour divided by average interior/exterior air-temperature difference over the same hour.

FIGURE C.2 DECAY HEAT LOSS TEST - BEFORE RETROFIT



Note: Light trace represents indoor air temperature; dark trace represents indoor relative humidity (not calibrated: use as indicator of trends only.

FIGURE C.3 DECAY HEAT LOSS TEST - AFTER RETROFIT



Note: Light trace represents indoor air temperature; dark trace represents indoor relative humidity (not calibrated: use as indicator of trends only.

C.4 Energy-Use Records

Table C.8 Monthly Natural Gas Consumption

Utility: Greater Winnipeg Gas Company
Residence: 353 Chalmers Avenue

Period	Consumption (m^3)*			
	1980	1981	1982	1983
January	637	549	773	
February	674	--	379	
March	657	--	527	
April	3	300 (3 mo.)		
May	102	133		
June	6	6		
July	62	62		
August	62	--		
September	6	28 (2 mo.)		
October	292	181		
November	178	277		
December	660	456		
Total	3338	1993	1679	
Cost	$366.57	$271.56	$239.17	

* Conversion from gas company data recorded to nearest one hundred cubic feet. Columns may not add up due to rounding.

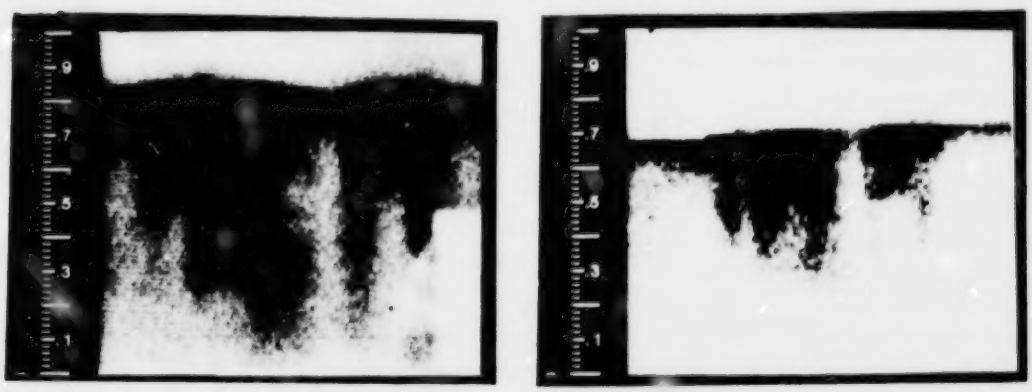
Table C.9 Monthly Electricity Consumption

Utility: Winnipeg Hydro
Residence: 353 Chalmers Avenue

Period	Consumption (kWh)			
	1980	1981	1982	1983
Jan 2 - Feb 2	815	657	1024	
Feb 2 - Mar 2	616	635	900	
Mar 2 - Apr 2	657	513		
Apr 2 - May 2	575	511		
May 2 - Jun 2	596	524		
Jun 2 - Jul 2	474	440		
Jul 2 - Aug 2	475	370		
Aug 2 - Sep 2	431	439		
Sep 2 - Oct 2	482	473		
Oct 2 - Nov 2	624	546		
Nov 2 - Dec 2	741	617		
Dec 2 - Jan 2	835	1041		
Total	7321	6766	1924	

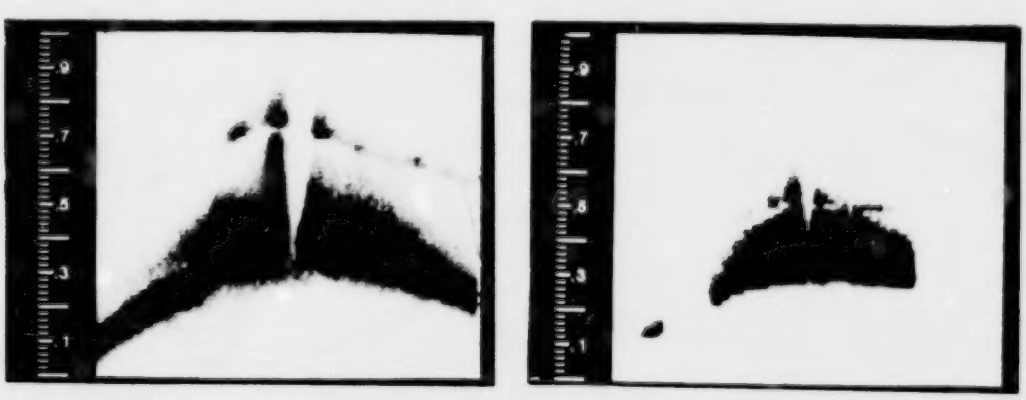
C.5 Thermography

The following photographs are selected from the results of thermographic scans of the interior of the building envelope and are representative of the major problems in the house.



(a) (b)

FIGURE C.4 Migration of Top-Plate Air Leakage: (a) Before re-insulation of walls; (b) After re-insulation.



(a) (b)

FIGURE C.5 Air Infiltration at Sill Plate: (a) Before re-insulation of walls; (b) After re-insulation.

D.1 General Information

Identification

Address:	460 St. Jean Baptiste Street, Winnipeg, Man. R2H 2X7

Residence Description

Type of Home:	Single, detached
Year of Construction:	1920-1930
No. of Storeys:	One
Wall Construction:	Wood frame
Type of Foundation:	Basement
No. of Residents:	2

Thermostat

Setting:	Day: 22.8°C* Evening: 22.8°C Night: 22.8°C (Manual)
Test:	Measured interior temp.: 22.8°C Cut-in: 22.8°C

Domestic Hot Water

Type of System:	Natural gas
Tank:	Capacity: 114 l Insulation: 25 mm
Measured Temp.:	60.6°C
Daily Use:	General: 45 l/person Washer: 15 l/person Dishwasher: 10 l/person

Space Heating

Type of System:	Natural gas forced air
Furnace:	Anthes LGB112 (25V AC controls)
Age:	15 to 20 years (estimated)
Rated Specifications:	Input: 32.8 kW** Output: 26.4 kW**
Fan Operation:	Noncontinuous Cut-in: 58.9°C
Chimney:	Masonry, interior (inside east foundation wall)

Miscellaneous

Basement:	Temperature: 17.8°C Humidity: 46%
Dryer Venting:	Outdoors
Winter Humidifier Use:	Regular
Current Problems:	Draughts, cold rooms, cracked basement walls admit water, loose-fitting basement windows.

* Unless otherwise indicated, all temperatures are conversions from field data recorded to nearest degree Fahrenheit. No further accuracy is implied.

** Conversion from nameplate specification in Btu/hr.

D.2 Building Description

Component: Assembly (approx.)		RSI[1] Before/After
Basement:		
Floors: Poured concrete		4.4
Walls: Poured concrete, 0.6 m above grade, 1.5 m below grade, uninsulated		0.8
Main Floor:		
West Wall:		
Outside air film		0.03
Stucco		0.03
Softwood sheathing		0.17
89 mm wall cavity:	15% structural softwood (RSI 0.77) with 85% wood shavings (RSI 1.51)	1.32
Interior finish - drywall		0.08
Interior air film		0.12
		1.75
Remaining Walls:		
Outside air film		0.03
Stucco		0.03
Softwood sheathing		0.17
89 mm wall cavity:	15% structural softwood (RSI 0.77) with 85% air (RSI 0.18) or blown cellulose (RSI 2.23)	0.20/1.74
Interior finish - mostly drywall		0.08
Interior air film		0.12
		0.63/2.17
Doors: Inner door with aluminum storm outdoor door		0.7
Windows: Double pane		0.35
Attic (vented):		
Attic air film		0.08
330 mm blown fibreglass added		0/4.95
Softwocd subfloor		0.10
89 mm joist space:	10% structural softwood (RSI 0.77) with 90% wood shavings (RSI 1.51)	1.36
Interior finish - mostly drywall		0.08
Inside air film		0.11
		1.75/6.70

[1] Tables 3.2 and 12.1, Handbook on: Insulating Homes for Energy Conservation, Canadian General Standards Board CGSB 51-GP-42MP, Ottawa, July, 1980.

Envelope Summary:

Component	Dimensions (m)	Area (m^2)	RSI
Basement floor:	8.5x7.3+3.7x2.4	70.9	4.4
Basement walls:	36.6x2.1	76.9	0.8
Main floor west wall:	7.3x2.4	17.5	1.75
- less door	1 @ 1.75 m^2	1.75	0.7
- less windows	4 @ 1 m^2	4.0	0.35
Main floor remaining walls:			
	29.3x2.4	70.3	0.63/2.17
- less door	1 @ 0.5 m^2,		
- less windows	2 @ 1 m^2,		
	1 @ 1.5 m^2	4.0	0.35
Main floor attic:	8.5x7.3+3.7x2.4	70.9	1.75/6.70

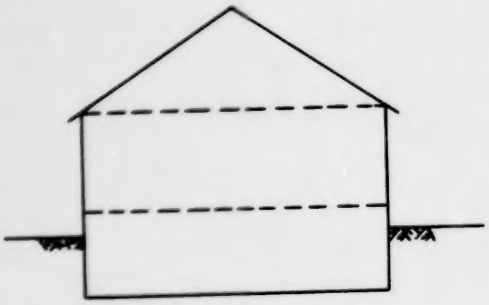
D.2 Building Description

Component: Assembly (approx.)		RSI[1] Before/After
Basement:		
Floors: Poured concrete		4.4
Walls: Poured concrete, 0.6 m above grade, 1.5 m below grade, uninsulated		0.8
Main Floor:		
West Wall:		
Outside air film		0.03
Stucco		0.03
Softwood sheathing		0.17
89 mm wall cavity:	15% structural softwood (RSI 0.77) with 85% wood shavings (RSI 1.51)	1.32
Interior finish - drywall		0.08
Interior air film		0.12
		1.75
Remaining Walls:		
Outside air film		0.03
Stucco		0.03
Softwood sheathing		0.17
89 mm wall cavity:	15% structural softwood (RSI 0.77) with 85% air (RSI 0.18) or blown cellulose (RSI 2.23)	0.20/1.74
Interior finish - mostly drywall		0.08
Interior air film		0.12
		0.63/2.17
Doors: Inner door with aluminum storm outdoor door		0.7
Windows: Double pane		0.35
Attic (vented):		
Attic air film		0.08
330 mm blown fibreglass added		0/4.95
Softwood subfloor		0.10
89 mm joist space:	10% structural softwood (RSI 0.77) with 90% wood shavings (RSI 1.51)	1.36
Interior finish - mostly drywall		0.08
Inside air film		0.11
		1.75/6.70

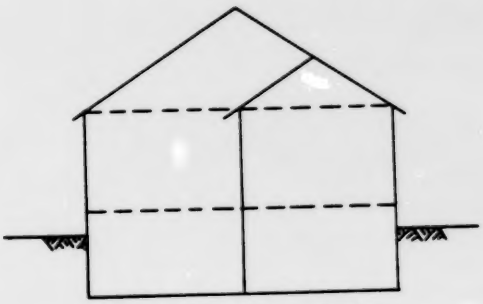
[1] Tables 3.2 and 12.1, Handbook on: Insulating Homes for Energy Conservation, Canadian General Standards Board CGSB 51-GP-42MP, Ottawa, July, 1980.

Envelope Summary:

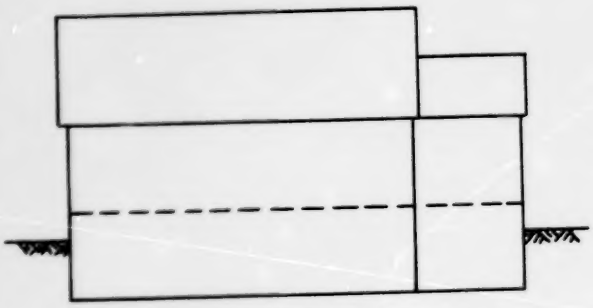
Component	Dimensions (m)	Area (m^2)	RSI
Basement floor:	8.5x7.3+3.7x2.4	70.9	4.4
Basement walls:	36.6x2.1	76.9	0.8
Main floor west wall:	7.3x2.4	17.5	1.75
- less door	1 @ 1.75 m^2	1.75	0.7
- less windows	4 @ 1 m^2	4.0	0.35
Main floor remaining walls:			
	29.3x2.4	70.3	0.63/2.17
- less door	1 @ 0.5 m^2,		
- less windows	2 @ 1 m^2,		
	1 @ 1.5 m^2	4.0	0.35
Main floor attic:	8.5x7.3+3.7x2.4	70.9	1.75/6.70



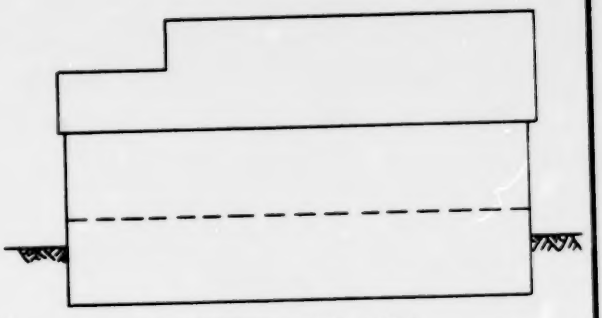
(a)WEST SIDE VIEW



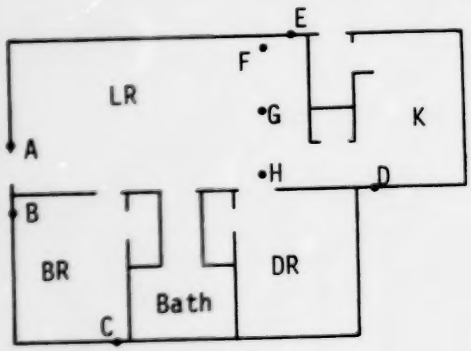
(b)EAST SIDE VIEW



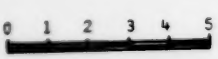
(c)SOUTH SIDE VIEW



(d)NORTH SIDE VIEW



(e)FIRST FLOOR PLAN VIEW



Scale in m

BUILDING SCHEMATICS

FIGURE D.1

D.3 Test Results

"Before" test	March 19, 1982, 13:30 to 18:00 hrs. Conditions: clear, -2°C, NW6 km/h
Retrofit	March 29, 30, April 2, 1982: Re-insulation of walls & attic
"After" test	April 5, 1982, 08:30 to 12:00 hrs. Conditions: clear, -6°C, N8 km/h

Table D.1 Steady-State Furnace Combustion Efficiency

Test	Flue-gas CO_2(%)	Temperature (°C)*	Efficiency(%)
Before	6.5	368	70
After	6.5	368	70

* Conversion from field data recorded to nearest 5°F.

Table D.2 Neutral Pressure Plane Location

Test	Furnace	Location of Neutral Pressure Plane
Before	off	All infiltration below ceiling, infiltration & exfiltration at attic hatch: NPP at attic hatch.
	on	All infiltration below ceiling, more infiltration than exfiltration at attic hatch: NPP slightly higher with furnace on.
After	off	Very light infiltration & exfiltration at attic hatch, infiltration dominating, all infiltration below ceiling: NPP near attic hatch level.
	on	All infiltration: NPP above ceiling.

Table D.3 Occasional Interior Air Temperature & Relative Humidity Measurements

Time	Temp.* (°C)	R.H.* (%)	Dry Bulb** (°C)	Wet Bulb** (°C)	R.H. (%)
03.18.18:00***	23.3	44			
03.19.07:05	21.7	49			
03.19.13:30	22.2	48	20.6	13.9	48
03.20.01:30	22.2	47			
03.20.10:00	21.7	46			
03.20.18:00	22.8	49			
03.21.10:00	22.2	48			
03.21.21:00	22.8	50			
03.22.09:00	22.2	51			
03.22.21:00	22.2	50			
03.23.09:20	22.2	49			
03.23.24:00	22.2	49			
03.24.09:00	21.7	48			
03.24.17:35	22.2	47			
03.25.18:30	21.7	46			
03.25.23:00	21.7	46			
03.26.09:00	22.2	46			
03.26.21:00	21.7	45			
03.27.13:00	21.7	48			
03.27.23:00	22.2	47			
03.28.11:00	22.2	48			
03.28.24:00	22.8	54			
03.29.09:00	22.2	58			
RETROFIT					
03.29.22:00	23.3	58			
03.30.17:00	22.8	59			
03.30.24:00	22.8	58			
03.31.09:00	22.8	59			
03.31.22:00	22.2	57			
04.01.09:00	22.2	58			
04.01.22:00	22.2	56			
04.02.09:00	22.8	59			
04.02.22:00	22.2	55			
04.03.12:00	22.8	54			
04.03.22:00	22.8	54			
04.04.12:00	22.2	53			
04.04.24:00	22.2	53			
04.05.09:00	22.2	52	22.8	15.0	43
04.05.22:00	23.3	52			
04.06.10:30	22.2	51			
04.06.17:30			23.3	14.4	37
04.06.22:00	22.8	51			
04.07.07:30			24.4	14.4	32
04.07.09:30	22.2	52			

- Continued -

Table D.3 Occasional Interior Air Temperature & Relative Humidity Measurements (Continued)

Time	Temp.* (°C)	R.H.* (%)	Dry Bulb** (°C)	Wet Bulb** (°C)	R.H. (%)
04.07.23:00	22.8	50			
04.08.09:00	22.8	53			
04.08.24:00	22.2	51			
07.09.12:00	22.8	52			
07.09.22:00	22.8	56			
04.10.11:00	23.3	54			
04.10.17:00	23.3	52			

* Recorded by homeowner, central location, main floor.
** Recorded by project team, central location, main floor.
*** March 18, 18:00 hrs.

Table D.4 Surface & Air Temperatures On Interior Of Envelope (°C)

Test	Location	W1*	W2	W3	A1	C1	C2	C3
	A**	20.6	19.4	18.3	22.2			
	B	19.4	20.0	18.9	21.1			
	C	16.7	16.7	16.1	19.4			
Before	D	16.7	17.2	17.2	19.4			
03.19.14:00	E	19.4	20.0	18.9	21.7			
	F					21.1		
	G						21.1	
	H							21.1
	A	20.0	17.2	16.7	20.6			
	B	16.7	18.9	17.2	20.0			
	C	19.4	19.4	19.4	20.0			
After	D	20.6	20.6	20.6	21.1			
04.05.09:00	E	22.2	21.7	21.1	21.7			
	F					25.0		
	G						25.0	
	H							24.4

* W1: wall surface, 300 mm below ceiling.
W2: wall surface, 1.5 m above floor.
W3: wall surface, 300 mm above floor.
A1: air within 300 mm of wall, 1.5 m above floor.
C1: ceiling surface, 300 mm from exterior wall.
C2: ceiling surface, halfway to centre of ceiling.
C3: ceiling surface, near centre of ceiling.

** Locations indicated in Figure C.1 (e).

Table D.5 Air Infiltration Test Results

Test	Before	After
Airtightness testing unit	Type B	Type B
Location	North door	North door
Temperature (°C)	-2	-6
Wind (km/h)	NW6	N8
Conditions	clear	clear
House volume (m^3)	326	326
Envelope above grade (m^2)	181	181
Procedure	CGSB 149-GP-10M Third Draft	CGSB 149-GP-10M Third Draft
Deviations	dryer, range, bathroom vents sealed; single outdoor pressure tap	dryer, range, bathroom vents sealed; single outdoor pressure tap
Results: $Q = C(\Delta p)^n$		
$C(l/s\text{-}Pa^n)$	45.0	30.6
n	0.620	0.636
Correlation coefficient r	0.999	0.9999
$ELA_{10}(m^2)$	0.0781	0.0553 (29.2% reduction)
(cm^2/m^2 of envelope)	4.31	3.06
AC/hr_{10}	2.07	1.47
AC/hr_{50}	5.62	4.12

Raw Data:

Pressures (Pa) House	Pressures (Pa) Nozzle	Air Flow (l/s)	Pressures (Pa) House	Pressures (Pa) Nozzle	Air Flow (l/s)
40	940	443	22	230	220
50	1220	504	40	500	324
60	1600	577	60	840	419
70	1900	629	80	1240	508
80	2190	675	100	1660	588
90	2590	734	120	2060	655
100	2950	783	130	2290	690
110	3310	829	140	2520	724
			150	2730	753
			160	2920	779
			170	3210	816
			181	3480	850
			190	3680	874

Table D.6 Furnace Cycling Time

Period Starting	Duration (h)	Degree-Days*	Wind** (km/h)	No. of Cycles Total	No. of Cycles /D-D	Burn Time (s)	Burn Time (s/D-D)
BEFORE							
03.18.18:00N***	13.08	15.5	13.7	54	3.47	13200	849
03.19.07:05	6.58	6.9	23.2	26	3.80	6320	923
03.20.01:30N	8.50	9.9	20.0	37	3.72	8560	861
03.20.10:00	8.00	6.7	28.8	36	5.41	7380	1110
03.20.18:00N	16.00	15.3	14.2	56	3.66	12380	809
03.21.10:00	11.00	7.4	17.2	34	4.58	7060	951
03.21.21:00N	12.00	11.6	4.6	42	3.63	9050	782
03.22.09:00	12.00	9.1	21.0	45	4.93	9660	1058
03.22.21:00N	12.33	9.7	13.0	46	4.77	9650	1000
03.23.09:20	14.67	10.8	17.8	52	4.84	10720	997
03.23.24:00N	9.00	8.9	36.2	36	4.05	8000	901
03.24.09:00	8.67	8.4	38.1	36	4.31	8120	972
03.25.23:00N	10.00	12.1	12.9	45	3.72	10690	883
03.26.09:00	12.00	11.3	11.9	44	3.90	9750	865
03.26.21:00	16.00	16.0	25.2	66	4.13	14920	934
03.27.13:00	10.00	7.4	46.5	35	4.70	7530	1012
03.27.23:00N	12.00	8.5	28.0	42	4.93	9100	1068
03.28.11:00	13.00	6.8	10.8	29	4.25	5810	851
03.28.24:00N	9.00	5.7	24.6	26	4.60	5620	995
TOTAL	213.83	187.8	20.4	787	4.19	173520	924
"N" Only	101.92	97.2	17.7	384	3.95	86250	888
AFTER							
04.03.12:00	10.00	12.4	41.3	27	2.19	5700	462
04.03.22:00N	14.00	19.7	11.4	47	2.38	10550	535
04.04.12:00	12.00	13.4	12.3	31	2.32	6120	458
04.04.24:00N	9.00	11.7	10.1	28	2.39	6100	520
04.05.22:00N	12.5	14.9	5.0	36	2.41	7500	502
04.06.10:30	11.5	11.0	7.6	27	2.46	5430	495
04.07.23:00N	10.0	8.7	10.0	25	2.89	5220	603
04.08.09:00	15.0	10.7	23.0	33	3.08	6830	638
04.08.24:00N	12.0	8.8	23.7	30	3.41	6210	705
04.09.12:00	10.0	7.6	28.0	19	2.51	3880	512
04.09.22:00N	13.0	12.7	29.8	34	2.68	7150	564
04.10.11:00	6.0	4.7	13.5	14	2.96	2920	617
TOTAL	148.5	147.0	16.9	386	2.63	80850	550
Percent Change					-37.3		-40.5
"N" Only	70.5	76.5	15.4	200	2.61	42730	558
Percent Change					-33.9		-37.1

* Degree-Days (D-D) calculated from +18°C base using unofficial hourly temperatures for Winnipeg International Airport.

** Average windspeed in period, based on unofficial hourly windspeeds for Winnipeg International Airport.

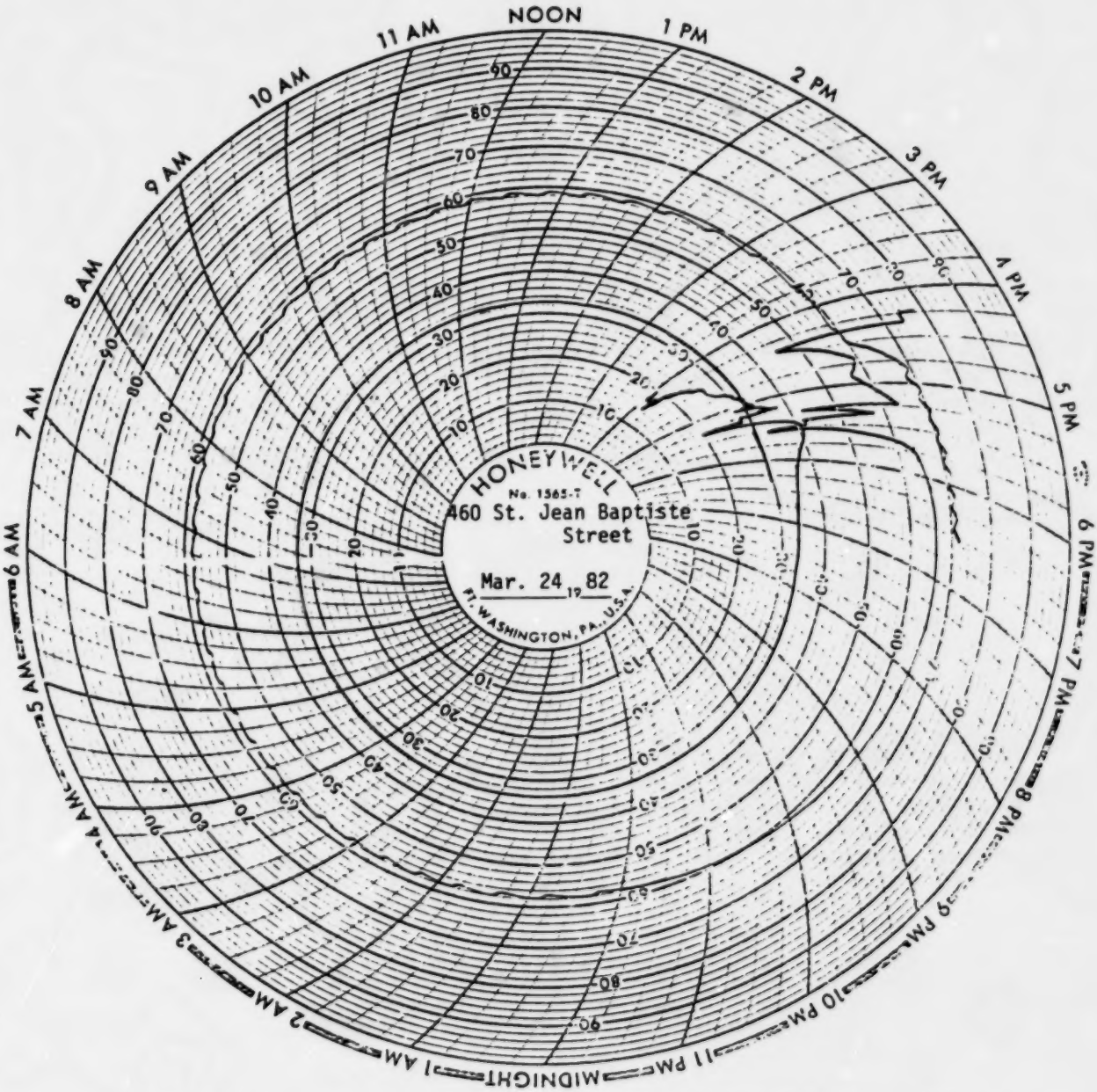
*** Symbol "N" denotes overnight measurement period (occupant activity and solar effects minimal).

Table D.7 Decay Heat Loss

Test	Before	After
Start	82.03.24.17:45	82.04.06.23:00
Finish	82.03.25.00:15	82.04.07.06:30
Occupants	Absent	Present
Furnace Fan	Off	Off
Exterior Air Temperature (°C)*:		
Start	-3.7	-6.4
Finish	-9.5	-8.7
Mean - during test	-6.6	-7.9
Mean - preceding 24 h	-4.0	-7.7
Windspeed Indicator (km/h)**:		
Start	35	0
Finish	20	7
Mean - during test	24.2	5.1
Mean - preceding 24 h	34.1	5.5
Relative cooling rate (h^{-1})***:		
Hour: 1	-	0.0400
2	-	0.0265
3	0.0417	0.0288
4	0.0439	0.0229
5	0.0419	0.0255
6	0.0421	0.0212
7	-	0.0211

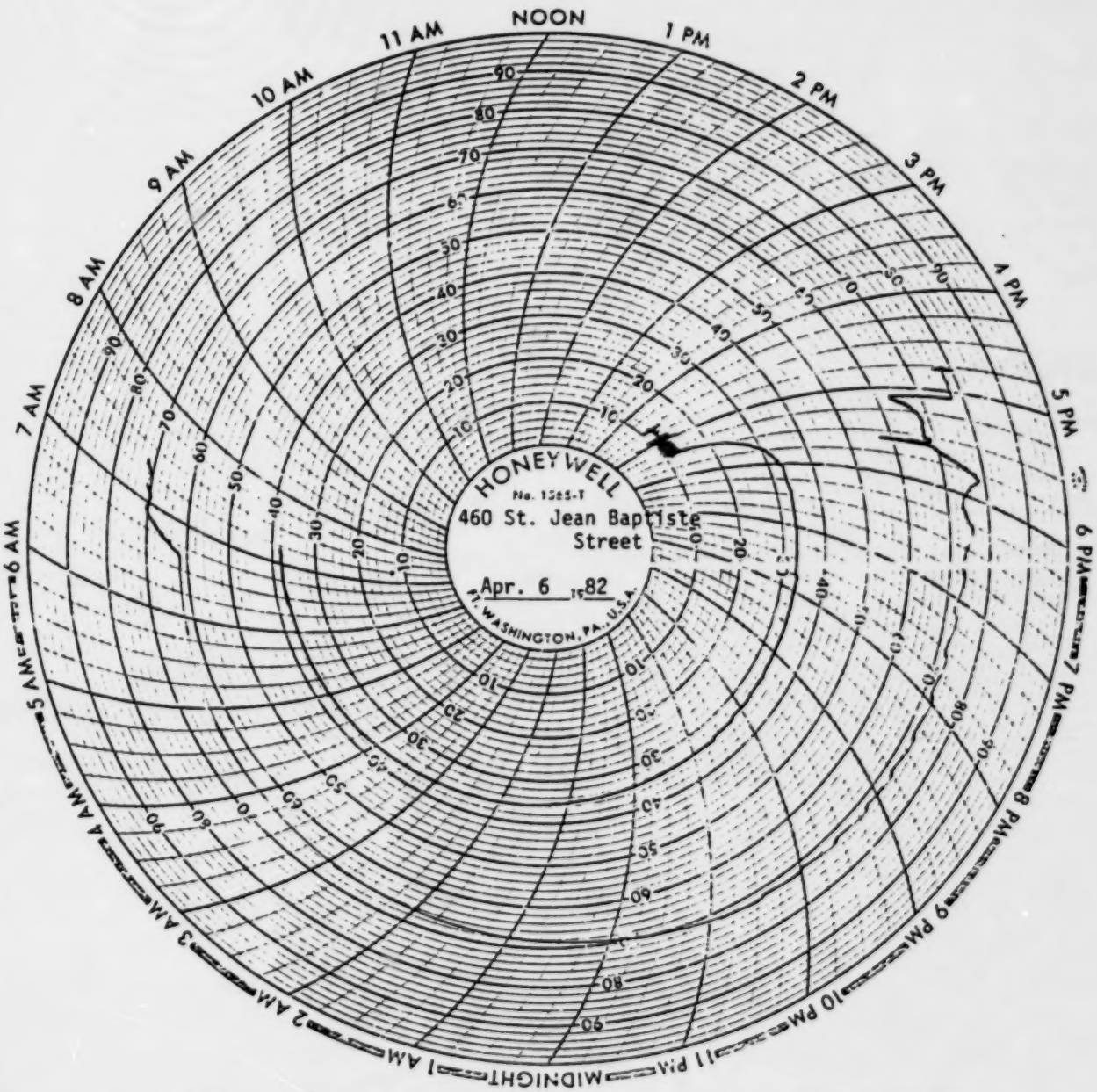
* Based on unofficial hourly temperatures for Winnipeg International Airport.
** Based on unofficial hourly windspeeds for Winnipeg International Airport: to be used for comparison only because actual windspeeds near the building are significantly lower.
*** Interior air-temperature drop over one hour divided by average interior/exterior air-temperature difference over the same hour.

FIGURE D.2 DECAY HEAT LOSS TEST - BEFORE RETROFIT



Note: Light trace represents indoor air temperature; dark trace represents indoor relative humidity (not calibrated: use as indicator of trends only.

FIGURE D.3 DECAY HEAT LOSS TEST - AFTER RETROFIT



Note: Light trace represents indoor air temperature; dark trace represents indoor relative humidity (not calibrated: use as indicator of trends only.

D.4 Energy-Use Records

Table D.8 Monthly Natural Gas Consumption

Utility: Greater Winnipeg Gas Company
Residence: 460 St. Jean Baptiste Street

Period	Consumption (m^3)*			
	1980	1981	1982	1983
January	810	759	1158	
February	782	770	801	
March	770	484	603	
April	238	600		
May	343	212		
June	108	198		
July	68	91		
August	105	93		
September	178	105		
October	218	439		
November	609	354		
December	595	716		
Total	4822	4822	2563	
Cost	$516.30	$630.18	$360.67	

* Conversion from gas company data recorded to nearest one hundred cubic feet. Columns may not add up due to rounding.

Table D.9 Monthly Electricity Consumption

Utility: Manitoba Hydro
Residence: 460 St. Jean Baptiste Street

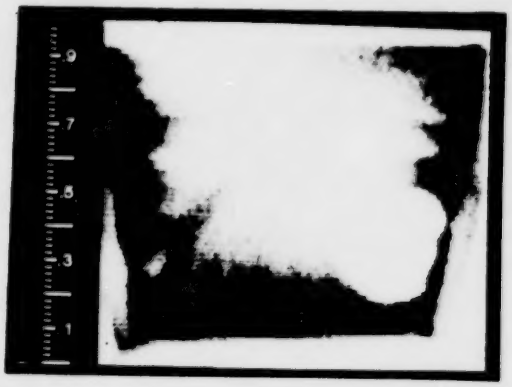
Period	Consumption (kWh)			
	1980	1981	1982	1983
December				
January	1490(60)*	1420(62)	1410(62)	
February				
March	1490(58)	1260(63)	1360(65)	
April				
May	960(61)	780(51)		
June				
July	810(58)	880(62)		
August				
September	910(63)	920(64)		
October				
November	930(61)	990(61)		
Total	6590(361)	6250(363)	2770(127)	

* Number of days between readings.

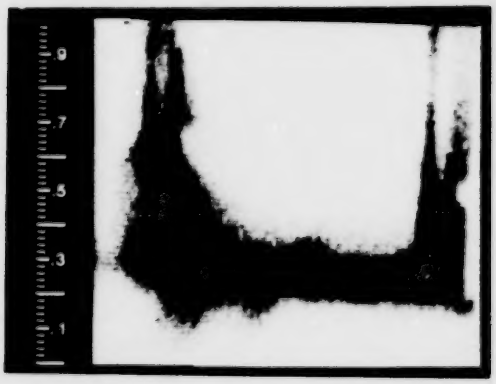
D.5 Thermography

The following photographs are selected from the results of thermographic scans of the interior of the building envelope and are representative of the major problems in the house.

(a)



(b)



(c)

FIGURE D.4 Air Leakage at Intentional Openings in Building Envelope: (a) Range exhaust fan; (b) Attic hatch; (c) Door.

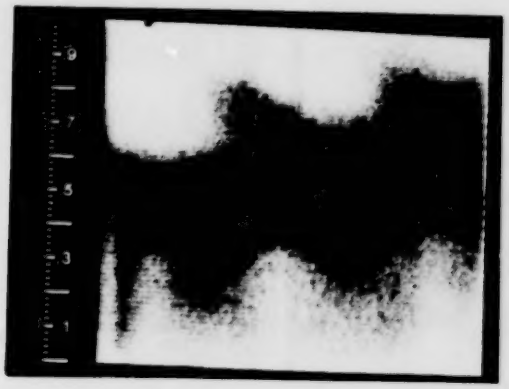
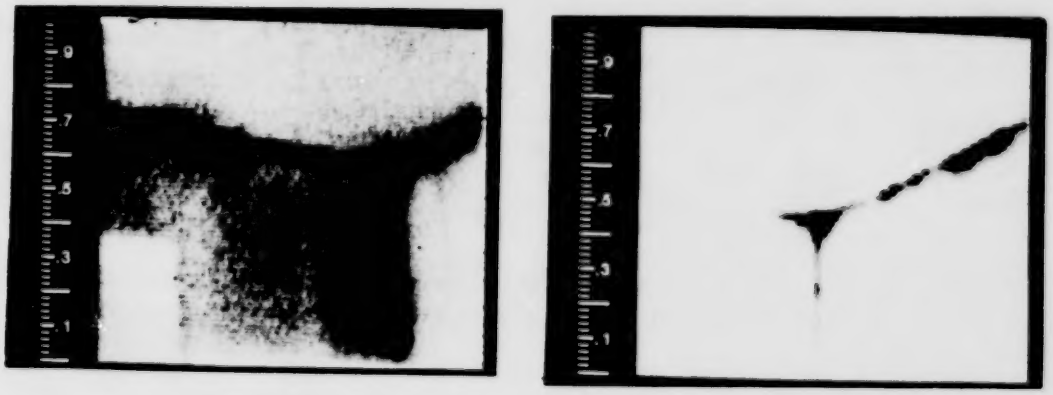
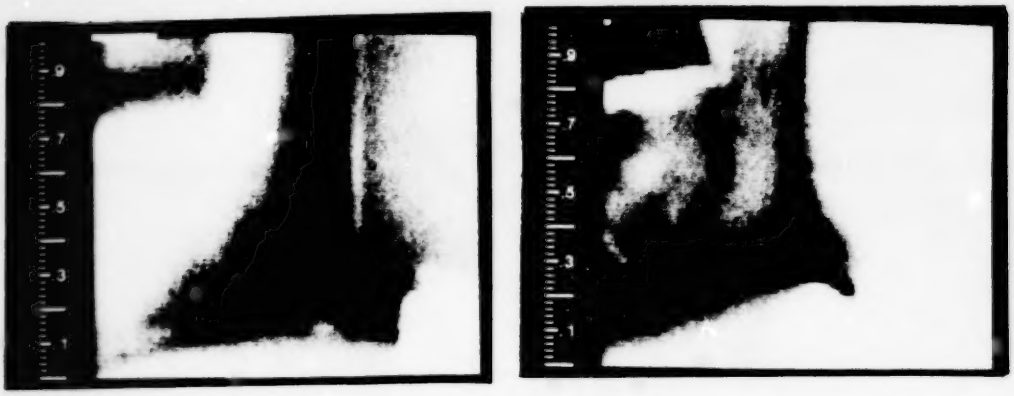


FIGURE D.5 Air Leakage at Top Plate and Migration in Ceiling and Wall Stud Cavities Prior to Re-insulation.



(a) (b)

FIGURE D.6 Effect of Re-insulation of Exterior Walls and Ceiling: (a) Before re-insulation; (b) After re-insulation.



(a) (b)

FIGURE D.7 Air Infiltration at Sill Plate and Through Crack at Junction of Exterior Walls: (a) Before re-insulation of walls and ceiling; (b) After re-insulation.

E.1 General Information

Identification

Address:	822 Talbot Avenue, Winnipeg, Man.

Residence Description

Type of Home:	Single, detached
Year of Construction:	1945
No. of Storeys:	One and one-half
Wall Construction:	Wood frame
Type of Foundation:	Basement
No. of Residents:	3

Thermostat

Setting:	Day: 19°C Evening: 19°C Night: 16°C (Manual, °C)
Test:	Measured interior temp.: 20.6°C* Cut-in: 21°C

Domestic Hot Water

Type of System:	Natural gas
Tank:	Capacity: 114 l Insulation: 25 mm
Measured Temp.:	55.6°C
Daily Use:	General: 20 l/person Washer: 15 l/person Baths/wk: 1 Showers/wk: 5

Space Heating

Type of System:	Natural gas forced air
Furnace:	Crane GL125 (millivolt controls)
Age:	16 to 20 years (estimated)
Rated Specifications:	Input: 36.6 kW** Output: 29.3 kW**
Fan Operation:	Noncontinuous Cut-in: 62.8°C Cut-out: 40.6°C
Chimney:	Masonry, central

Miscellaneous

Basement:	Temperature: 16.1°C Humidity: 36%
Dryer Venting:	Outdoors
Winter Humidifier Use:	Vaporizer on second floor only
Current Problems:	Leaky doors, cold floors near envelope

* Unless otherwise indicated, all temperatures are conversions from field data recorded to nearest degree Fahrenheit. No further accuracy is implied.

** Conversion from nameplate specification in Btu/hr.

E.2 Building Description

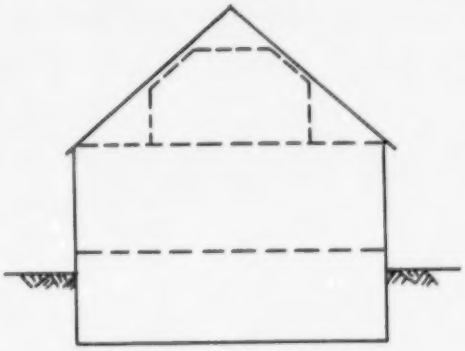
Component: Assembly (approx.)		RSI[1] Before/After
Basement:		
Floors:	Poured concrete	4.4
Walls:	Poured concrete, framed & insulated (winter 1981-82) to full depth with fibreglass batts (RSI 2.1) 0.6 m above grade, 1.7 m below	2.9
Main Floor:		
Walls:	Outside air film	0.03
	Stucco	0.03
	Softwood sheathing	0.17
	89 mm wall cavity: 15% structural softwood (RSI 0.77) with 85% air (RSI 0.18) or blown cellulose (RSI 2.23)	0.20/1.74
	Interior finish - drywall	0.08
	Interior air film	0.12
		0.63/2.17
Doors:	Inner door with aluminum storm outdoor door	0.7
Windows:	Double pane	0.35
Ceiling (unvented side attics):		
	Attic air film	0.08
	Subfloor - softwood	0.17
	140 mm joist space with 50 mm wood shavings	0.85
	Interior finish - drywall	0.08
	Inside air film	0.11
		1.29
Second Floor:		
Gable-end Walls:		
	Same as main floor walls	0.63/2.17
Windows:	Double pane	0.35
Knee wall:		
	Side attic air film	0.08
	89 mm stud wall: 15% structural softwood (RSI 0.77) with 85% fibreglass batts (RSI 2.1)	1.67
	Interior finish - drywall	0.08
	Interior air film	0.12
		1.95

[1] Tables 3.2 and 12.1, Handbook on: Insulating Homes for Energy Conservation, Canadian General Standards Board CGSB 51-GP-42MP, Ottawa, July 1980.

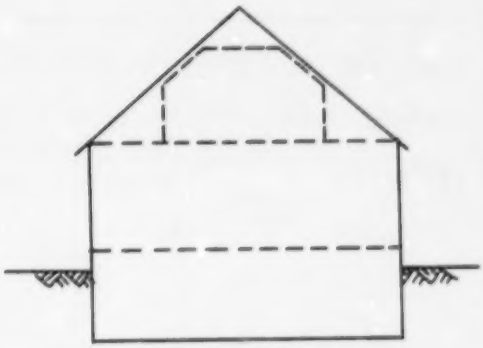
Component: Assembly (approx.)	RSI
Sloped ceiling:	
Outside air film	0.03
Asphalt shingles	0.08
Roof sheathing	0.14
89 mm rafter space: 10% structural softwood (RSI 0.77) with 90% wood wool (RSI 2.05)	1.76
Interior finish - drywall	0.08
Interior air film	0.11
	2.20
Side attic end walls (unvented):	
Outside air film	0.03
Stucco	0.03
Softwood sheathing	0.17
89 mm stud wall: 15% structural softwood (RSI 0.77) with 85% fibre-glass batts (RSI 1.96)	1.59
Side attic air film:	0.08
	1.90
Side attic roof (unvented):	
Outside air film	0.03
Asphalt shingles	0.08
Roof sheathing	0.14
Side attic air film	0.08
	0.33
Attic (vented):	
Attic air film	0.08
330 mm blown fibreglass	4.95
89 mm joist space: 10% structural softwood (RSI 0.77) with 90% wood wool (RSI 2.05)	1.76
Interior finish - drywall	0.08
Interior air film	0.11
	6.98

Envelope Summary:

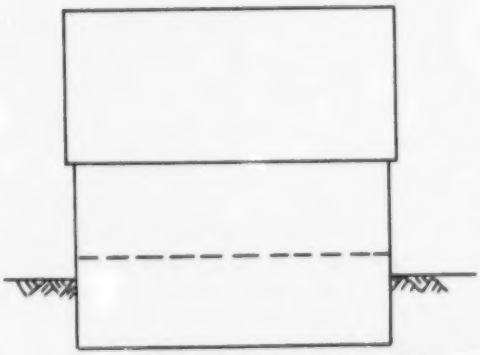
Component	Dimensions (m)	Area (m^2)	RSI
Basement floor:	7.3x7.3	53.3	4.4
Basement walls:	29.2x2.3	67.2	2.9
Main floor walls:	29.2x2.4	70.1	0.63/2.17
- less doors	2 @ 1.75 m^2	3.5	0.7
- less windows	1 @ 1.5 m^2, 4 @ 0.5 m^2	3.5	0.35
Main floor ceiling: side attic	2(7.3 x 1.8)	26.3	1.29
Second floor gable end walls:	2(3.7x2.3-1.2)	14.6	0.63/2.17
- less windows	2 @ 1.5 m^2	3.0	0.35
Second floor knee walls:	7.3x1.2+6.3x1.2 +2(1.8x1.2x0.5)	18.4	1.95
Second floor sloped ceiling:	2.2x1.0+2(1.6x7.3)	25.6	2.20
Second floor attic:	7.3x3.7	27.0	6.98
Side attic end walls:	4(1.8x1.2x0.5)	4.3	1.90
Side attic roof:	7.3x2.2+6.3x2.2	29.9	0.33



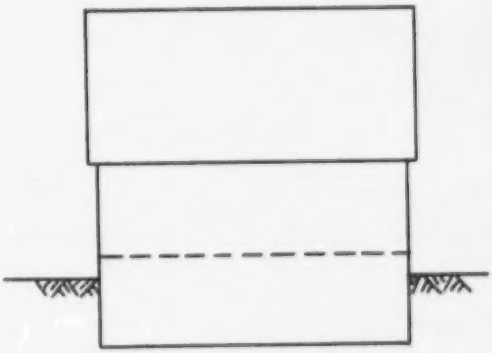
(a)NORTH SIDE VIEW



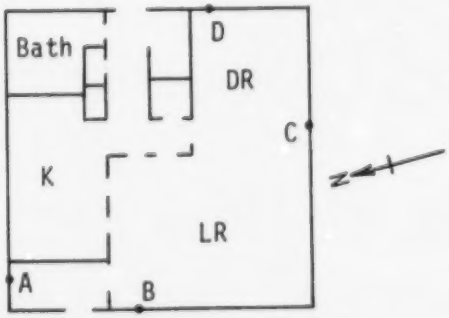
(b)SOUTH SIDE VIEW



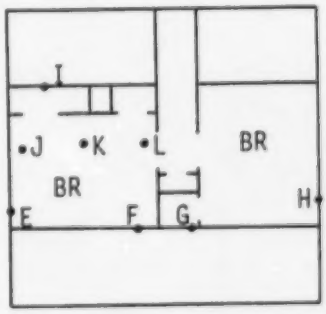
(c)WEST SIDE VIEW



(d)EAST SIDE VIEW



(e)FIRST FLOOR PLAN VIEW



(f)SECOND FLOOR PLAN VIEW

Scale in m

BUILDING SCHEMATICS

FIGURE E.1

E.3 Test Results

"Before" test	March 26, 1982, 8:45 to 12:00 hrs. Conditions: clear, -1°C, SE5 km/h
Retrofit	March 31, 1982: Re-insulation of Main Floor Walls, Second Floor End Walls
"After" test	April 7, 1982, 8:45 to 12:00 hrs. Conditions: clear, -2°C, E4 km/h

Table E.1 Steady-State Furnace Combustion Efficiency

Test	Flue-gas CO_2(%)	Temperature (°C)*	Efficiency(%)
Before	9.0	360	73.5
After	9.0	318	75.5

* Conversion from field data recorded to nearest 5°F.

Table E.2 Neutral Pressure Plane Location

Test	Furnace	Location of Neutral Pressure Plane
Before	off	Infiltration on all walls, infiltration and exfiltration at attic hatch: NPP at second floor level
	on	Same as above.
After	off	Infiltration on all walls, majority of movement at attic hatch is exfiltration: NPP at second floor ceiling level.
	on	Wall infiltration stronger than above, infiltration and exfiltration at attic hatch approximately equal: NPP slightly higher than above.

Table E.3 Occasional Interior Air Temperature & Relative Humidity Measurements

Time	Temp.* (°C)	R.H.* (%)	Dry Bulb** (°C)	Wet Bulb** (°C)	R.H. (%)
03.24.11:45***	17.2	56			
03.24.18:00	20.0	60			
03.25.09:00	18.9	55			
03.25.17:00	20.0	60			
03.26.07.30	18.9	50			
03.26.09:00			17.2(17.5)***	10.6(10.6)	43(41)
03.26.17:30	20.0	60			
03.27.09:15	20.0	52			
03.27.21:55	18.9	52			
03.28.12:10	19.4	60			
03.29.09:30	18.3	58			
03.29.18:00	20.0	62			
03.30.10:10	20.0	60			
03.30.17:35	20.0	66			
03.31.10:35	19.4	57			
RETROFIT					
03.31.20:30	18.9	60			
04.01.09:30	20.0	54			
04.02.10:15	20.0	58			
04.02.18:00	20.0	60			
04.03.09:50	18.9	54			
04.03.19:00	20.6	53			
04.05.09:00	20.0	52			
04.05.18:45	20.0	56			
04.06.10:15	20.0	50			
04.06.19:30	19.4	56			
04.07.09:00	20.0	54	22.2(21.7)	13.3(13.3)	56(56)
04.07.17:30	20.0	58			
04.08.08:30	17.8	56			
04.10.07:45	20.0	57			
04.10.17:30	20.0	59			

* Recorded by homeowner, central location, main floor.
** Recorded by project team, central location, main floor.
*** March 24, 11:45 hrs.
**** Second Floor.

Table E.4 Surface & Air Temperatures On Interior Of Envelope (°C)

Test	Location	W1*	W2	W3	A1	C1	C2	C3
Before 03.26.09:00	A**	16.7	16.7	16.1	19.4			
	B	16.7	16.1	16.1	17.8			
	C	15.6	15.6	15.0	15.6			
	D	18.3	17.2	16.7	20.6			
	E	15.0	16.1	13.9	16.7			
	F***	16.7	13.9	13.9	16.7			
	G***	16.7	15.0	12.2	17.2			
	H	14.4	15.6	14.4	16.7			
	I***	16.1	16.1	15.0	17.2			
	J					16.1		
	K						17.2	
	L							17.8
After 04.07.09:00	A	16.7	17.8	16.1	17.8			
	B	17.8	17.8	17.8	18.3			
	C	18.3	18.3	17.8	18.3			
	D	17.8	17.2	18.3	18.3			
	E	16.1	15.6	15.6	17.2			
	F***	18.3	15.0	15.6	17.8			
	G***	15.0	15.6	14.4	19.4			
	H	15.0	16.1	16.1	18.3			
	I***	17.8	16.1	16.1	17.2			
	J					17.2		
	K						18.3	
	L							18.3

* W1: wall surface, 300 mm below ceiling.
W2: wall surface, 1.5 m above floor.
W3: wall surface, 300 mm above floor.
A1: air within 300 mm of wall, 1.5 m above floor.
C1: ceiling surface, 300 mm from exterior wall.
C2: ceiling surface, halfway to centre of ceiling.
C3: ceiling surface, near centre of ceiling.

** Locations indicated in Figure B.1 (e,f).

*** W1 located on sloped ceiling; W2, W3 on knee wall.

Table E.5 Air Infiltration Test Results

Test	Before	After
Airtightness testing unit	Type B	Type B
Location	West door	West door
Temperature (°C)	-1	0
Wind (km/h)	SE5	E4
Conditions	clear	clear
House volume (m^3)	303	303
Envelope above grade (m^2)	200	200
Procedure	CGSB 149-GP-10M Third Draft	CGSB 149-GP-10M Third Draft
Deviations	single outdoor pressure tap	single outdoor pressure tap
Results: $Q = C(\Delta p)^n$		
$C(l/s\text{-}Pa^n)$	55.5	54.5
n	0.646	0.634
Correlation coefficient r	0.9989	0.9996
$ELA_{10}(m^2)$	0.102	0.0974 (4.6% reduction)
(cm^2/m^2 of envelope)	5.11	4.87
AC/hr_{10}	2.92	2.79
AC/hr_{50}	8.27	7.73

Raw Data:

Pressures (Pa) House	Nozzle	Air Flow (l/s)	Pressures (Pa) House	Nozzle	Air Flow (l/s)
10	270	238	10	270	238
15	520	330	15	440	304
20	740	393	20	590	351
25	940	443	25	850	421
30	1150	490	30	1080	475
35	1450	550	35	1300	521
40	1750	604	40	1510	561
45	2050	653	45	1770	607
50	2440	712	50	2040	651
55	2650	742	55	2320	694
60	2860	771	60	2570	731
65	3250	821	65	2840	768
70	3550	858	70	3130	806
			75	3450	846
			80	3670	872

Note: Wall-cavity access holes not re-stuccoed.

Table E.5 (continued)

Test	After Wall-Cavity Holes Sealed (82.06.03.09:30)
Airtightness testing unit	Type B
Location	West door
Temperature (°C)	+12
Wind (km/h)	S15
Conditions	clear
House volume (m^3)	303
Envelope above grade (m^2)	200
Procedure	CGSB 149-GP-10M Third Draft
Deviations	single outdoor pressure tap
Results: $Q = C(\Delta p)^n$	
$C(l/s\text{-}Pa^n)$	61.6
n	0.605
Correlation coefficient r	0.9990
$ELA_{10}(m^2)$	0.100
(cm^2/m^2 of envelope)	5.01
AC/hr_{10}	2.95
AC/hr_{50}	7.79

Raw Data:

Pressures (Pa) House	Nozzle	Air Flow (l/s)
10	290	247
15	470	314
20	710	385
25	910	436
30	1070	472
35	1350	530
40	1630	583
45	1730	600
50	2090	659
55	2490	719

Table E.6 Furnace Cycling Time

Period Starting	Duration (h)	Degree-Days*	Wind** (km/h)	No. of Cycles Total	No. of Cycles /D-D	Burn Time (s)	Burn Time (s/D-D)
BEFORE							
03.24.11:45	6.25	5.8	37.6	10	1.72	3190	550
03.24.18:00N***	15.0	17.4	18.5	23	1.32	9760	562
03.25.09:00	8.0	8.2	11.8	9	1.09	3700	450
03.25.17:00N	14.5	16.6	14.8	21	1.27	9130	551
03.27.09:15	12.67	9.6	49.2	14	1.46	5100	533
03.27.21:55N	14.25	10.0	28.1	15	1.50	5710	572
03.28.12:10	21.33	12.1	17.0	11	0.91	4020	331
03.29.09:30	8.5	4.7	33.9	7	1.51	3040	654
03.29.18:00N	16.17	9.4	26.5	12	1.28	4280	455
03.30.10:10	7.42	4.2	15.3	3	0.71	1260	300
03.30.17:35N	17.0	12.6	40.5	19	1.51	7220	574
TOTAL	141.08	110.5	26.4	144	1.30	56410	511
"N" Only	76.92	65.9	26.1	90	1.37	36100	548
AFTER							
03.31.20:30N	13.0	14.5	20.3	21	1.44	8280	569
04.01.09:30	24.75	21.6	26.9	24	1.11	9400	435
04.02.10:15	7.75	8.0	50.9	9	1.13	4090	514
04.02.18:00N	15.83	20.4	53.7	24	1.18	10370	509
04.03.09:50	9.17	11.2	47.5	13	1.16	5580	498
04.03.19:00	38.0	46.7	13.1	49	1.05	22840	489
04.05.09:00	9.75	10.6	18.0	12	1.14	3720	353
04.05.18:45N	15.5	18.2	7.3	25	1.37	9830	539
04.06.10:15	9.25	8.7	7.7	6	0.69	1900	218
04.06.19:30N	13.5	14.0	5.3	14	1.00	7500	536
04.08.08:30	47.25	37.0	26.1	34	0.92	15060	407
04.10.07:45	9.75	8.3	16.2	8	0.97	2950	358
TOTAL	213.5	219.1	23.1	239	1.09	101520	463
Percent Change					-19.5		-9.2
"N"Only	57.83	67.1	22.5	84	1.25	35980	536
Percent Change					-8.4		-2.2

* Degree-Days (D-D) calculated from +18 °C base using unofficial hourly temperatures for Winnipeg International Airport.

** Average windspeed in period, based on unofficial hourly windspeeds for Winnipeg International Airport.

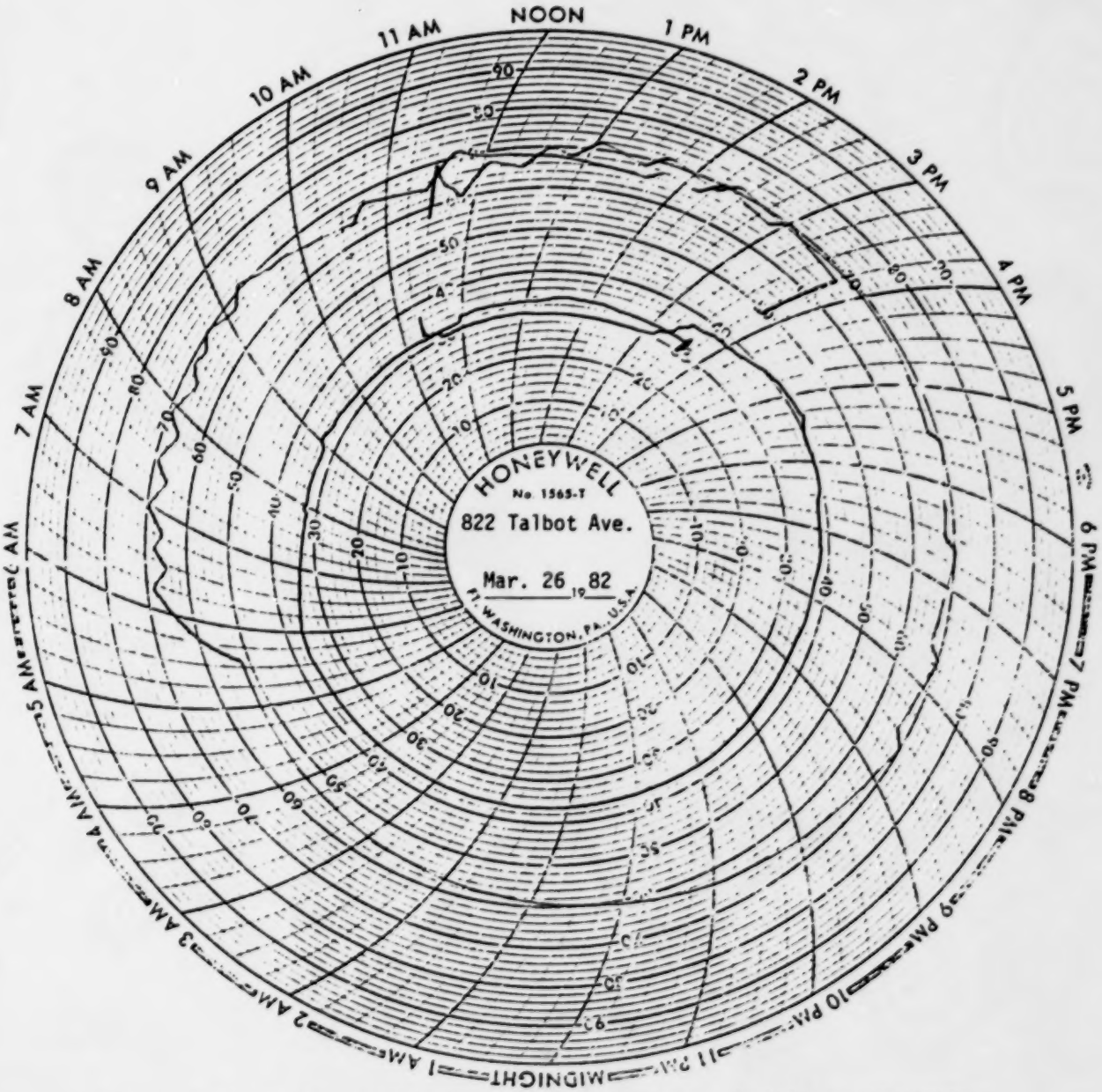
*** Symbol "N" denotes overnight measurement period (occupant activity and solar effects minimal).

Table E.7 Decay Heat Loss

Test	Before	After
Start	82.03.26.20:45	82.04.07.21:45
Finish	82.03.27.05:30	82.04.08.05:15
Occupants	Present	Present
Furnace Fan	Off	Off
Exterior Air Temperature (°C)*:		
Start	-5.8	-2.7
Finish	-8.7	-3.2
Mean - during test	-7.2	-3.4
Mean - preceding 24 h	-8.9	-4.0
Windspeed Indicator (km/h)**:		
Start	13	7
Finish	21	7
Mean - during test	17.1	8.6
Mean - preceding 24 h	12.6	4.4
Relative cooling rate (h-1)***:		
Hour: 1	0.0689	0.0701
2	0.0498	0.0455
3	0.0525	0.0449
4	0.0496	0.0440
5	0.0507	0.0370
6	0.0441	0.0351
7	0.0452	0.0399
8	0.0410	-

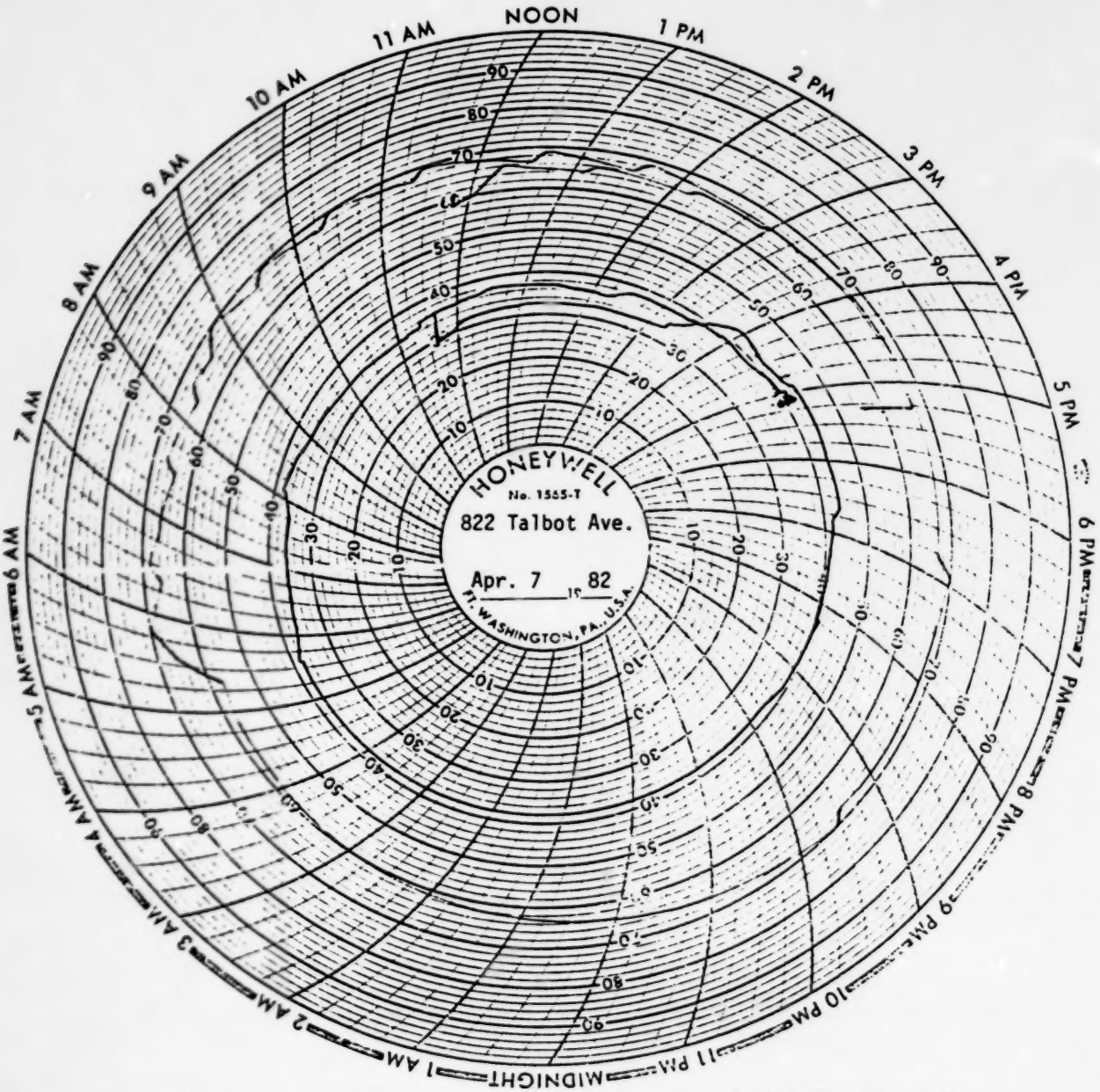
* Based on unofficial hourly temperatures for Winnipeg International Airport.
** Based on unofficial hourly windspeeds for Winnipeg International Airport: to be used for comparison only because actual windspeeds near the building are significantly lower.
*** Interior air-temperature drop over one hour divided by average interior/exterior air-temperature difference over the same hour.

FIGURE E.2 DECAY HEAT LOSS TEST - BEFORE RETROFIT



Note: Light trace represents indoor air temperature; dark trace represents indoor relative humidity (not calibrated: use as indicator of trends only.

FIGURE E.3 DECAY HEAT LOSS TEST - AFTER RETROFIT



Note: Light trace represents indoor air temperature; dark trace represents indoor relative humidity (not calibrated: use as indicator of trends only.

E.4 Energy-Use Records

Table E.8 Monthly Natural Gas Consumption

Utility: Greater Winnipeg Gas Company
Residence: 822 Talbot Avenue

Period	Consumption (m^3)*			
	1980	1981	1982	1983
January	51	379	844	
February	1028	589	626	
March	855	328	462	
April	476	515		
May	Vacant	147		
June	Vacant	108		
July	Vacant	93		
August	Vacant	71		
September	235	130		
October	255	289		
November	348	300		
December	872	674		
Total	4120	3624	1931	
Cost	$459.58	$482.97	$272.66	

* Conversion from gas company data recorded to nearest one hundred cubic feet. Columns may not add up due to rounding.

Table E.9 Monthly Electricity Consumption

Utility: Winnipeg Hydro
Residence: 822 Talbot Avenue

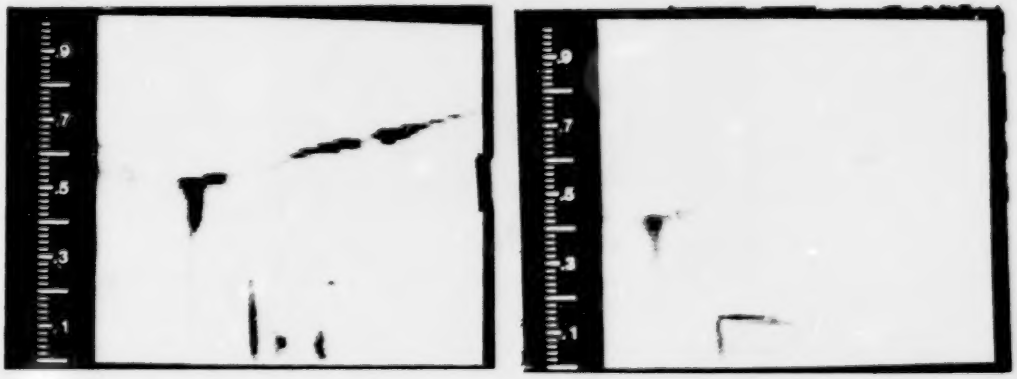
Period	Consumption (kWh)			
	1980	1981	1982	1983
Jan 7 - Feb 7	453	538	904	
Feb 7 - Mar 7	461	395*	812	
Mar 7 - Apr 7	495	102**		
Apr 7 - May 7	426	122		
May 7 - Jun 7	415	363		
Jun 7 - Jul 7	395	487		
Jul 7 - Aug 7	323	463		
Aug 7 - Sep 7	418	377		
Sep 7 - Oct 7	372	392		
Oct 7 - Nov 7	465	462		
Nov 7 - Dec 7	500	574		
Dec 7 - Jan 7	662	776		
Total	5385	5051	1716	

* Feb 7 - Mar 1, 1981; final bill for previous occupants.
** Mar 15 - Apr 7, 1981; initial bill for present occupants.

E.5 Thermography

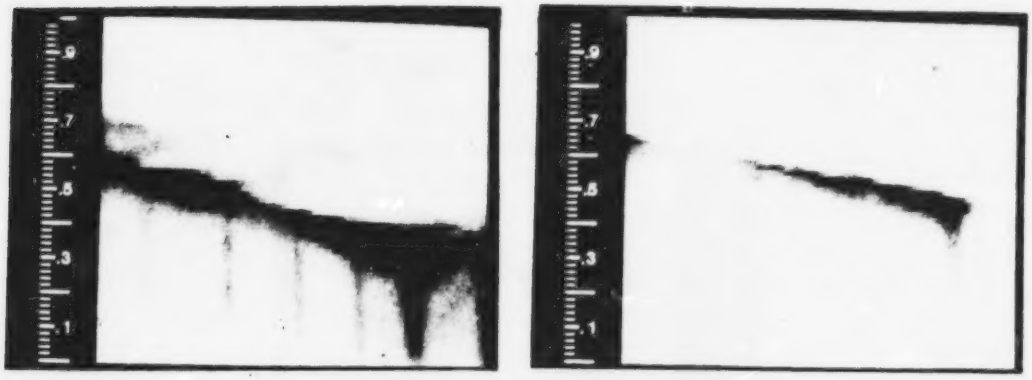
The following photographs are selected from the results of thermographic scans of the interior of the building envelope and are representative of the major problems in the house.

FIGURE E.4 Air Leakage Through Attic Hatch



(a) (b)

FIGURE E.5 Migration and Entry Along Interior Partition Wall of Cold Air Originating from Exterior Wall at Left: (a) Before re-insulation of exterior walls; (b) After re-insulation.



(a) (b)

FIGURE E.6 Air Infiltration at Top Plate of Exterior Walls: (a) Before re-insulation of walls; (b) After re-insulation.

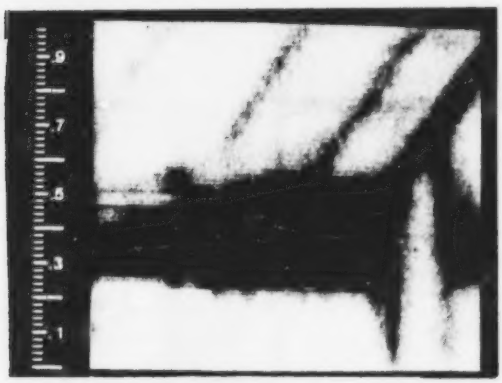
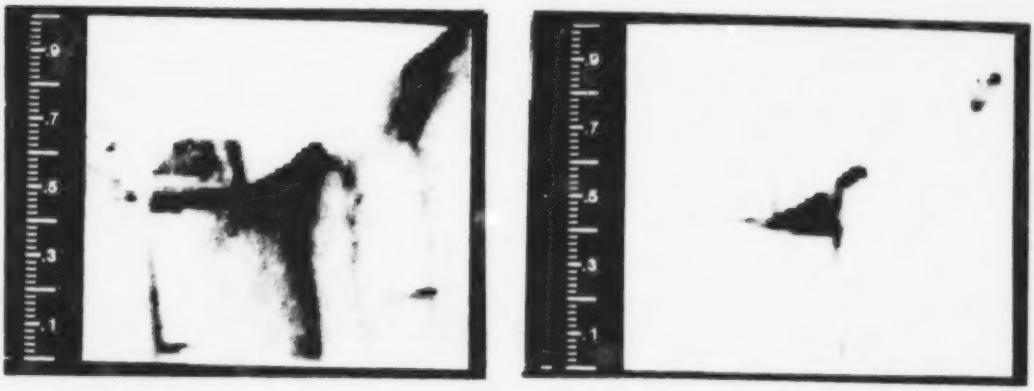


FIGURE E.7 Inadequate Coverage of Glass-Fibre Batts on Kneewall.



(a) (b)

FIGURE E.8 Air Leakage at Sill Plate as Seen From Partially Finished Basement Below: (a) Before re-insulation of main-floor walls; (b) After re-insulation.

2F.1 General Information

Identification	
Address:	380 Queen Street, Winnipeg, Man. R3J 1L1
Residence Description	
Type of Home:	Single, detached
Year of Construction:	1925 (approx.)
No. of Storeys:	One and one-half
Wall Construction:	Wood frame
Type of Foundation:	Crawl space with partial basement
No. of Residents:	3
Thermostat	
Setting:	Day: 20°C Evening: 20°C Night: 15°C (Manual, °C)
Test:	Measured interior temp.: 20.0°C* Cut-in: 20°C
Domestic Hot Water	
Type of System:	Natural gas
Tank:	Capacity: 150 l Insulation: 25 mm
Measured Temp.:	61.7°C
Daily Use:	General: 45 l/person Washer: 15 l/person
Space Heating	
Type of System:	Natural gas forced air
Furnace:	Homart C875 (millivolt controls)
Age:	16 to 20 years (estimated)
Rated Specifications:	Input: 23.4 kW** Output: 18.7 kW**
Fan Operation:	Continuous (may be faulty): Cut-in: 51.7°C, 11°C difference)
Chimney:	Masonry, interior on inside of west foundation wall
Miscellaneous	
Basement:	Temperature: 17.2°C Humidity: 39%
Dryer Venting:	Outdoors
Winter Humidifier Use:	Some
Current Problems:	Draughts, cold rooms, leaky windows, leaky joint between main part of house and rear addition, furnace fan runs continuously.

* Unless otherwise indicated, all temperatures are conversions from field data recorded to nearest degree Fahrenheit. No further accuracy is implied.

** Conversion from nameplate specification in Btu/hr.

F.2 Building Description

Component: Assembly (approx.)	RSI[1] Before/After
Basement:	4.4
Floor: Poured concrete	
Walls: Poured & block concrete, 200 mm thickness, all below grade uninsulated	2.0(rough approximation)
Crawl Space	3.0(rough approximation)
Floor: earth, 0.7 m below grade	
Crawl space perimeter: concrete, 0.3 m above grade, 0.5 m below grade, insulated on inside with RSI 2.1 fibreglass batts (late 1981)	1.7
Main floor east wall:	
Veranda air film	0.08
Hardboard siding	0.10
Softwood sheathing	0.17
89 mm wall cavity: 15% structural softwood (RSI 0.77) with 85% air (RSI 0.18) or blown cellulose (RSI 2.23)	0.20/1.74
Interior finish - lath & plaster	0.12
Interior air film	0.12
	0.79/2.33
Door: Inner door with wooden storm outer door	0.7
Window: Double pane	0.35
North, South, Main West Walls: Same as east wall, except no veranda; RSI of outside air film reduced	0.74/2.28
	0.35
Windows: Double pane	
Back Room Walls:	
Outside air film	0.03
Hardboard siding	0.10
Softwood sheathing	0.17
89 mm wall cavity: 15% structural softwood (RSI 0.77) with 85% air space and 64 mm fibreglass batts (RSI 0.18+1.4)	1.36(to be upgraded '82)
Interior finish - drywall	0.08
Inside air film	0.12
	1.86

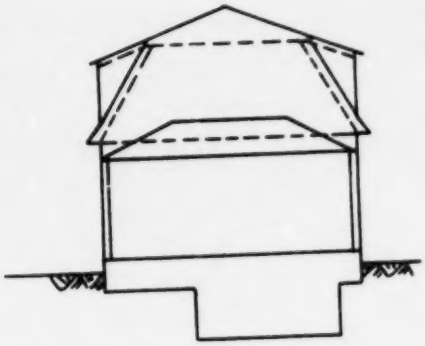
[1] Tables 3.2 and 12.1, Handbook on: Insulating for Energy Conservation, Canadian General Standards Board CGSB 51-GP-42MP, Ottawa, July 1980.

Component:	Assembly (approx.)	RSI
Door:	Inner door with wooden outdoor storm door	0.7
Window:	Double pane	0.35
Back Room	Attic (unvented):	
	Outside air film	0.03
	Asphalt roofing	0.08
	Roof sheathing	0.14
	Attic air films (2 @ 0.08)	0.16
	Joist space: 10% structural softwood (RSI 0.56) with 90% fibre-glass batts (RSI 1.4) (estimated)	1.14(to be upgraded '82)
	Interior finish - drywall	0.08
	Interior air film	0.11
		1.74
Back Room	Floor:	
	Crawl space air film	0.08
	Joist space: 10% structural softwood (RSI 0.56) with 90% 64 mm fibreglass batts (RSI 1.4)	1.14 (estimated)
	Floor sheathing	0.17
	Tile	0.01
	Interior air film	0.11
		1.51
Exposed ceiling	(unvented side attics):	
	Attic air film	0.08
	Joist space with some wood fibre	0.80
	Interior finish - lath & plaster	0.12
	Interior air film	0.11
		1.11
Second floor:		
East, West, dormer walls:		
	Outside air film	0.03
	Hardboard siding	0.10
	Softwood sheathing	0.17
	89 mm wall cavity: 15% structural softwood (RSI 0.77) with 85% air (RSI 0.18) or blown cellulose (RSI 2.23)	0.20/1.74
	Interior finish - lath & plaster	0.12
	Interior air film	0.12
		0.74/2.28
Windows:	Double pane	0.35

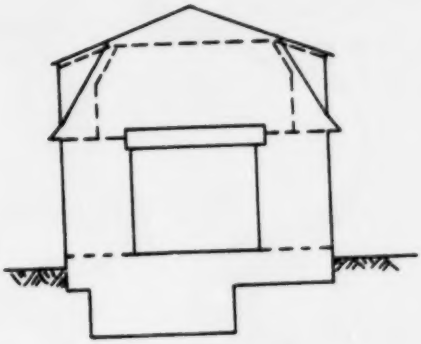
Component: Assembly (approx.)	RSI	
Sloped walls:		
(includes dormer ceiling)		
Outside air film	0.03	
Asphalt shingles	0.08	
Roof sheathing	0.14	
89 mm rafter space: 10% structural softwood (RSI 0.77) with 90% wood fibre (RSI 2.05)	1.76	
Interior finish - lath & plaster	0.12	
Inside air film	0.11	
	2.24	
Knee Walls (unvented):		
Side attic air film	0.08	
Stud wall with interior finish - lath & plaster	0.12	
Interior air film	0.12	
	0.32	
Side attic end walls (unvented):		
Air film, siding, sheathing, air film	0.38	
Side attic roof (unvented):		
Outside air film	0.03	
Asphalt shingles	0.08	
Roof sheathing	0.14	
Side attic air film	0.08	
	0.33	
Attic (vented):		
Attic air film	0.08	
280 mm blown fibreglass	4.20	(summer '80)
89 mm joist spacing: 10% structural softwood (RSI 0.77) with 90% wood fibre (RSI 2.05)	1.76	
Interior finish - lath & plaster	0.12	
Interior air film	0.11	
	6.27	

Envelope Summary:

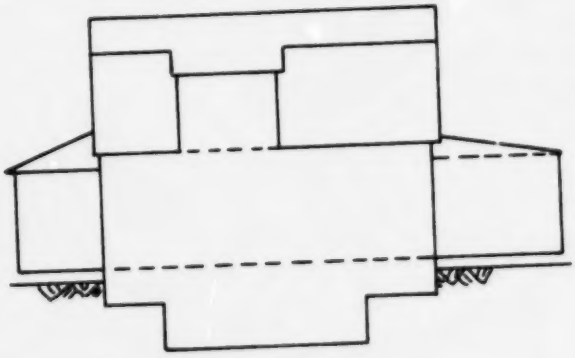
Component	Dimensions (m)	Area (m^2)	RSI
Basement floor:	4.6 x 3.4	15.6	4.4
walls	16.0 x 1.2	19.2	2.0
Crawl Space floor:	remainder of 7.9 x 6.2 basement	33.4	3.0
walls:	28.2 x 0.8	22.6	1.7
Main floor north, south, main west walls:	19.0 x 2.7	51.3	0.74/2.28
- less windows	1 @ 0.5 m^2, 2 @ 1.0 m^2	2.5	0.35
Main floor east wall:	6.2 x 2.7	16.7	0.79/2.33
- less door	1 @ 1.75 m^2	1.75	0.7
- less window	1 @ 1.0 m^2	1.0	0.35
Main floor back room walls:	9.0 x 2.3	20.7	1.86
- less window	1 @ 1.0 m^2	1.0	0.35
- less door	1 @ 1.75 m^2	1.75	0.7
Main floor back room attic:	3.0 x 3.0	9.0	1.74
Main floor back room floor:	3.0 x 3.0	9.0	1.51
Main floor exposed ceiling:	2 @ 3.6x0.8	5.8	1.11
Second floor end walls, dormers	2 @ (6.2x2.4-0.5) 2(1.9x2.3)	37.5	0.74/2.28
- less windows	6 @ 1.0 m^2	6.0	0.35
Second floor knee walls:	2 @ 3.6x1.4	10.1	0.32
Second floor side attic end walls	2 @ 0.5x0.8x1.4	1.1	0.38
Second floor side attic roof:	2 @ 3.6x1.6	11.5	0.33
Second floor sloped walls:	2(2.0x2.8) + 2(3.6x1.1)	19.1	2.24
Second floor attic:	3.5 x 7.9	27.7	6.27
Second floor dormer ceiling:	2 @ 1.3x2.3	6.0	2.24



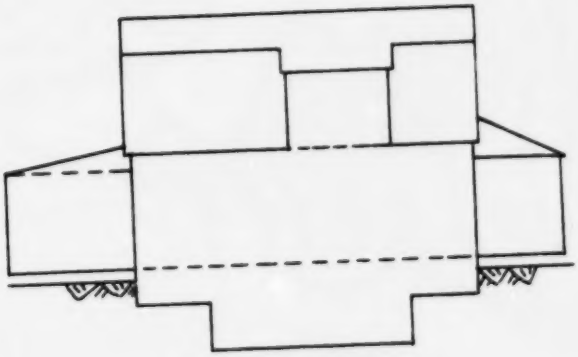
(a)EAST SIDE VIEW



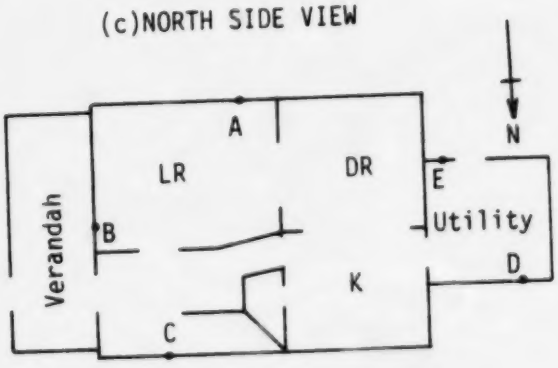
(b)WEST SIDE VIEW



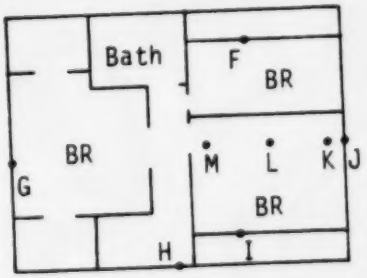
(c)NORTH SIDE VIEW



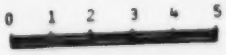
(d)SOUTH SIDE VIEW



(e)FIRST FLOOR PLAN VIEW



(f)SECOND FLOOR PLAN VIEW



Scale in m

BUILDING SCHEMATICS

FIGURE F.1

F.3 Test Results

"Before" test	March 26, 1982, 13:00 to 17:00 hrs. Conditions: clear, 0°C, E3 km/h
Retrofit	April 6,7, 1982: Re-insulation of vertical walls except for back room
"After" test	April 13, 1982, 08:15 to 12:00 hrs. Conditions: clear, clouding over during test, temperature rising from 3° to 9°C, SE8 km/h

Table F.1 Steady-State Furnace Combustion Efficiency

Test	Flue-gas CO_2(%)	Temperature (°C)*	Efficiency(%)
Before	8.0	310	74.5
After	8.0	349	72.5

* Conversion from field data recorded to nearest 5°F.

Table F.2 Neutral Pressure Plane Location

Test	Furnace	Location of Neutral Pressure Plane (NPP)
Before	off	Infiltration on main & second floor walls, except for west windows on second floor which have some exfiltration near their tops mixed with a majority of infiltration, both infiltration & exfiltration at attic hatch with the latter dominating: NPP at second floor ceiling level, lower on west side.
	on	Infiltration on all walls except tops of west windows which have some exfiltration, infiltration only at attic hatch: NPP raised above ceiling level, except on west side.
After	off	Infiltration on main & second floor walls except for west wall on second floor which has exfiltration above 1.0 m from floor and infiltration below that level, exfiltration at attic hatch: NPP at second floor ceiling, lower on west side.
	on	Same as above, except infiltration at attic hatch: NPP raised above ceiling level, except on west side.

Table F.3 Occasional Interior Air Temperature & Relative Humidity Measurements

Time	Temp.* (°C)	R.H.* (%)	Dry Bulb** (°C)	Wet Bulb** (°C)	R.H. (%)
03.24.09:45***			17.8	10.6	40
03.24.20:45	20.6	38			
03.25.06:30	18.3	35			
03.25.12:00	20.0	33			
03.25.21:50	20.0	35			
03.26.11:00	21.1	34			
03.26.13:00			20.0(20.0)****	11.1(11.1)	32
03.26.18:45	21.1	35			
03.26.22:55	22.2	35			
03.27.06:50	22.2	32			
03.27.10:35	21.1	34			
03.27.17:45	22.2	32			
03.27.22:20	22.2	30			
03.28.07:30	21.1	35			
03.28.12:20	22.2	36			
03.28.21:05	22.2	40			
03.29.09:50	22.2	35			
03.29.12:40	22.2	38			
03.30.16:30	22.2	40			
03.30.19:40	23.3	40			
03.31.08:05	20.0	32			
04.01.06:30	19.4	34			
04.01.12:05	22.2	34			
04.01.19:10	22.2	34			
04.02.06:00	20.0	34			
04.02.13:10	22.2	34			
04.02.16:50	22.2	32			
04.03.07:20	17.8	32			
04.03.11:20	22.2	32			
04.04.08:40	20.0	31			
04.04.12:15	21.1	31			
04.04.18:55	24.4	37			
04.05.06:25	20.0	31			
04.05.20:20	22.2	32			
04.06.06:30	20.0	35			
04.06.11:25	22.2	33			

- Continued -

Table F.3 Occasional Interior Air Temperature & Relative Humidity Measurements (Continued)

Time	Temp.* (°C)	R.H.* (%)	Dry Bulb** (°C)	Wet Bulb** (°C)	R.H. (%)
RETROFIT					
04.07.20:05	20.0	41			
04.08.07:20	12.2	42			
04.08.11:30	20.0	40			
04.08.17:50	20.0	44			
04.08.23:30	20.0	42			
04.09.06:55	20.0	40			
04.09.11:50	20.0	42			
04.09.21:00	20.6	42			
04.10.08:30	22.2	38			
04.10.20:30	22.2	36			
04.11.08:30	22.2	36			
04.11.12:25	22.2	36			
04.12.06:15	22.2	44			
04.12.11:00	22.2	45			
04.12.19:30	22.2	46			
04.13.07:30	18.3	47			
04.13.08:30			19.4(19.4)	13.9(14.4)	54/58
04.13.20:30	22.2	46			
04.14.13:30	20.0	48			

* Recorded by homeowner, main floor centre, homeowner's instrument.
** Recorded by project team, main floor centre.
*** March 24, 09:45 hrs.
**** Second floor.

Table F.4 Surface & Air Temperatures On Interior Of Envelope (°C)

Test	Location	W1*	W2	W3	A1	C1	C2	C3
Before 03.26.13:30	A**	17.8	16.7	16.1	17.2			
	B	18.3	17.8	17.8	18.3			
	C	15.0	15.0	14.4	17.2			
	D	17.2	16.1	14.4	18.3			
	E	17.2	17.2	15.6	18.3			
	F***	20.6	19.4	17.8	19.4****			
	G	16.1	16.1	15.0	17.2			
	H	16.1	15.0	16.1	17.2			
	I***	15.6	15.6	15.6	16.7			
	J	16.7	16.1	14.4	17.8			
	K					18.3		
	L						18.3	
	M							18.3
After 04.13.08:30	A	16.7	16.7	16.7	16.1			
	B	16.7	16.7	16.7	16.7			
	C	16.1	16.1	15.6	16.1			
	D	14.1	13.9	13.9	14.4			
	E	13.9	13.3	12.8	13.3			
	F***	17.2	16.7	16.1	18.3			
	G	18.9	18.3	17.2	19.4****			
	H	16.7	16.7	16.7	18.3			
	I***	16.1	16.1	16.1	17.2			
	J	17.8	17.8	16.7	17.2			
	K					17.8		
	L						17.8	
	M							18.3

* W1: wall surface, 300 mm below ceiling.
W2: wall surface, 1.5 m above floor.
W3: wall surface, 300 mm above floor.
A1: air within 300 mm of wall, 1.5 m above floor.
C1: ceiling surface, 300 mm from exterior wall.
C2: ceiling surface, halfway to centre of ceiling.
C3: ceiling surface, near centre of ceiling.

** Locations indicated in Figure C.1 (e).

*** W1 located on sloped ceiling; W2, W3 on knee wall.

**** Temperatures biased by solar gains.

Table F.5(a) Air Infiltration Test Results - Total Heated Space

Test	Before	After
Airtightness testing unit	Type B	Type B
Location	Rear door (west)	Rear door (west)
Temperature (°C)	0	+7
Wind (km/h)	E3	SE8
Conditions	clear	clear, clouding over during test
House volume (m^3)	303	303
Envelope above grade (m^2)	210	210
Procedure	CGSB 149-GP-10M Third Draft	CGSB 149-GP-10M Third Draft
Deviations	single outdoor pressure tap	single outdoor pressure tap
Results: $Q = C(\Delta p)^n$		
$C(l/s\text{-}Pa^n)$	97.0	75.5
n	0.662	0.666
Correlation coefficient r	0.997	0.998
$ELA_{10}(m^2)$	0.185	0.143 (22.5% reduction)
(cm^2/m^2 of envelope)	8.81	6.83
AC/hr_{10}	5.07	4.15
AC/hr_{50}	14.7	12.1

Raw Data:

Pressures (Pa) House	Nozzle	Air Flow (l/s)	Pressures (Pa) House	Nozzle	Air Flow (l/s)
6	420	297	10	540	336
8	650	369	12	710	385
10	970	450	14	950	445
12	1060	470	16	1170	494
14	1330	527	18	1350	530
16	1640	584	20	1550	568
18	1950	637	24	1860	622
20	2240	682	28	2360	700
22	2530	725	32	2700	749
25	2780	760	36	3190	814
			40	3690	875
			43	4000	911

Table F.5(b) Air Infiltration Test Results - Main Part of House, excluding Back Room

Test	Before	After
Airtightness testing unit	Type B	Type B
Location	Door at partition to back room	Door at partition to back room
Temperature (°C)	0	+7
Wind (km/h)	E3	SE8
Conditions	clear	clouding over after 24 hour clear period
House volume (m^3)	283	283
Envelope above grade (m^2)	179	179
Procedure	CGSB 149-GP-10M Third Draft	CGSB 149-GP-10M Third Draft
Deviations	single outdoor pressure tap	single outdoor pressure tap
Results: $Q = C(\Delta p)^n$		
$C(l/s\text{-}Pa^n)$	87.6	83.4
n	0.630	0.597
Correlation coefficient r	0.999	0.9997
$ELA_{10}(m^2)$	0.155	0.135 (13.1% reduction)
(cm^2/m^2 of envelope)	8.67	7.54
AC/hr_{10}	5.58	4.92
AC/hr_{50}	15.4	12.9

Raw Data:

Pressures (Pa) House	Pressures (Pa) Nozzle	Air Flow (l/s)	Pressures (Pa) House	Pressures (Pa) Nozzle	Air Flow (l/s)
12	820	414	10	530	333
16	1240	508	15	840	419
20	1630	583	20	1180	496
24	2000	645	25	1540	566
28	2510	722	30	1890	627
32	2890	775	35	2340	697
36	3380	837	40	2670	745
40	3820	890	45	3200	815
			50	3590	863
			55	4100	922

Table F.6 Furnace Cycling Time

Period Starting	Duration (h)	Degree-Days*	Wind** (km/h)	No. of Cycles Total	No. of Cycles /D-D	Burn Time (s)	Burn Time (s/D-D)
BEFORE							
03.24.09:45	11.0	10.5	35.2	164	15.6	14430	1369
03.24.20:45N***	9.75	11.6	17.6	163	14.1	13290	1149
03.25.06:30	15.33	16.4	13.3	214	13.1	16080	983
03.26.22:55N	7.92	8.5	19.0	158	18.5	14210	1664
03.27.06:50	15.5	12.4	42.2	166	13.4	10860	875
03.27.22:20N	9.17	6.8	32.9	141	20.6	9980	1459
03.28.07:30	13.58	7.3	11.1	100	13.8	6290	866
03.28.21:05N	12.75	7.9	23.8	156	19.7	10550	1335
03.29.09:50	2.83	1.6	35.9	22	13.8	1320	825
03.29.12:40	27.83	15.8	25.1	245	15.5	16980	1073
03.30.16:30	3.17	2.0	25.3	32	16.1	2400	1206
03.30.19:40N	12.42	9.0	40.4	179	19.8	12740	1412
03.31.08:05	22.42	22.8	35.1	368	16.2	33440	1468
04.01.06:30	12.67	12.3	22.4	212	17.2	18870	1528
04.01.19:10N	10.83	9.1	24.8	154	16.9	11020	1210
04.02.06:00	10.83	10.1	44.3	186	18.3	15790	1557
04.02.16:50	14.5	18.3	53.8	252	13.8	21510	1175
04.03.07:20	4.0	5.4	57.0	66	12.2	10060	1866
04.03.11:20	21.33	28.8	27.1	403	14.0	36680	1273
04.04.08:40	10.25	11.6	10.9	162	14.0	15490	1339
04.04.18:55N	11.5	14.3	10.6	171	12.0	14010	982
04.05.06:25	13.92	15.6	16.7	232	14.9	17450	1119
04.05.20:20N	10.17	12.4	8.0	147	11.9	17630	1423
04.06.06:30	4.92	5.3	2.7	91	17.1	10470	1964
Total	288.58	275.9	26.6	4184	15.2	351550	1274
"N" Only	84.5	79.6	22.5	1269	15.9	103430	1299
AFTER							
04.07.20:05N	11.25	9.9	9.8	81	8.2	5180	524
04.08.07:20	16.17	11.6	22.[illegible]	170	14.6	13620	1170
04.08.23:30N	7.42	5.6	25.4	95	16.9	7380	1313
04.09.06:55	14.08	10.2	24.9	103	10.1	8160	799
04.09.21:00N	11.5	11.2	31.9	158	14.1	14400	1285
04.10.08:30	12.0	9.9	13.5	136	13.8	11420	1156
04.10.20:30N	12.0	10.8	15.9	143	13.3	11180	1036
04.11.08:30	3.92	2.5	41.9	31	12.6	2650	1080
04.11.12:25	17.83	9.8	35.4	133	13.6	9960	1015
Total	106.17	81.5	23.8	1050	12.9	83950	1030
Percent Change					-15.0		-19.1
"N" Only	42.17	37.5	20.3	477	12.7	38140	1017
Percent Change					-20.2		-21.7

* Degree-Days (D-D) calculated from +18°C base using unofficial hourly temperatures for Winnipeg International Airport.

** Average windspeed in period, based on unofficial hourly windspeeds for Winnipeg International Airport.

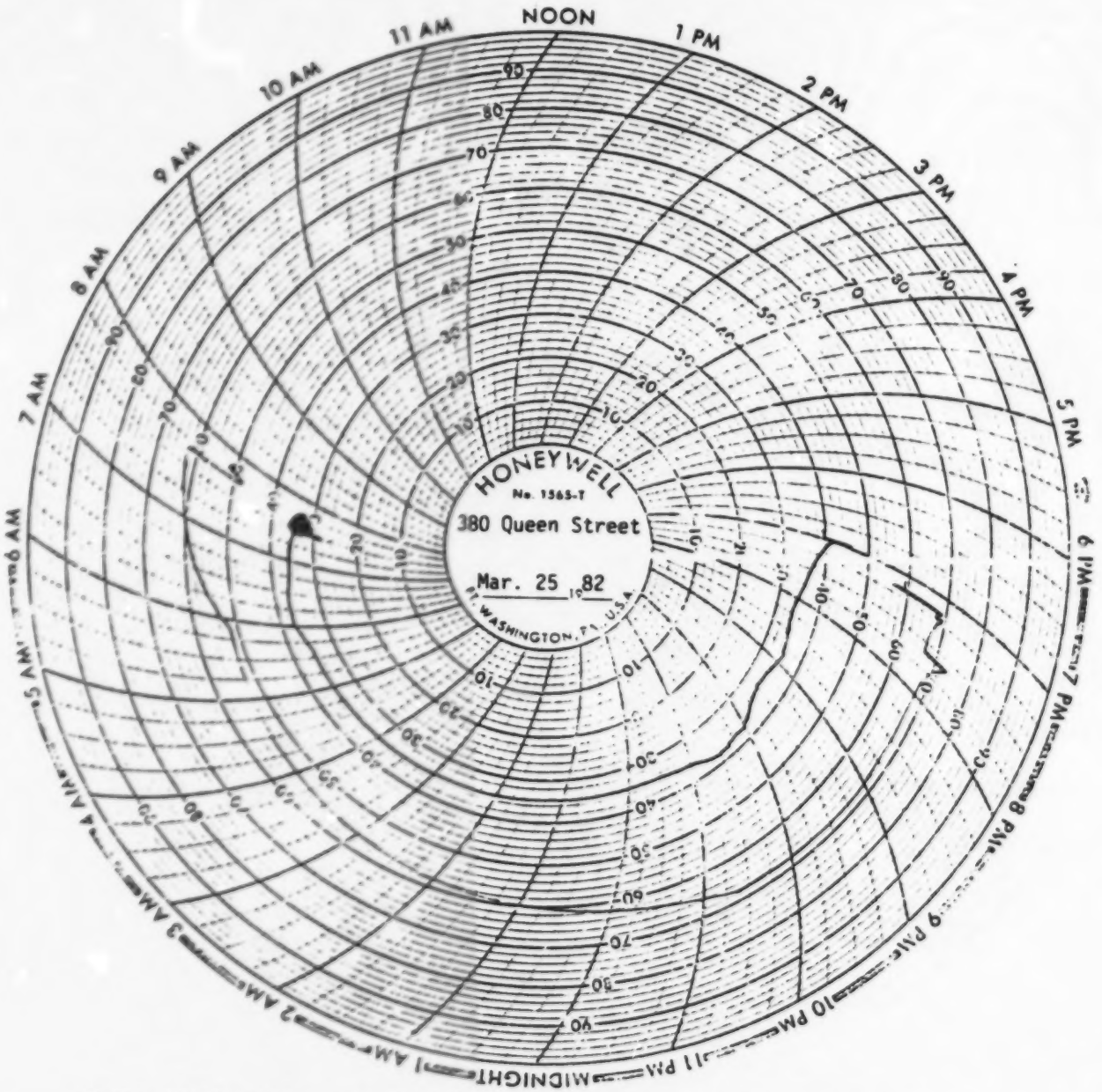
*** Symbol "N" denotes overnight measurement period (occupant activity and solar effects minimal).

Table F.7 Decay Heat Loss

Test	Before	After
Start	82.03.25.22:45	82.04.13.22:45
Finish	82.03.26.05:50	82.04.14.06:25
Occupants	Present	Present
Furnace Fan	On	On
Exterior Air Temperature (°C)*:		
Start	- 8.3	+3.7
Finish	-12.7	+2.6
Mean - during test	-10.5	+3.2
Mean - preceding 24 h	- 8.7	+2.5
Windspeed Indicator (km/h)**:		
Start	15	26
Finish	13	31
Mean - during test	14.1	28.2
Mean - preceding 24 h	14.4	13.5
Relative cooling rate (h^{-1})***:		
Hour: 1	0.0910	0.0647
2	0.0543	0.0411
3	0.0444	0.0424
4	0.0382	0.0248
5	0.0387	0.0321
6	0.0370	0.0257
7	0.0350	0.0298

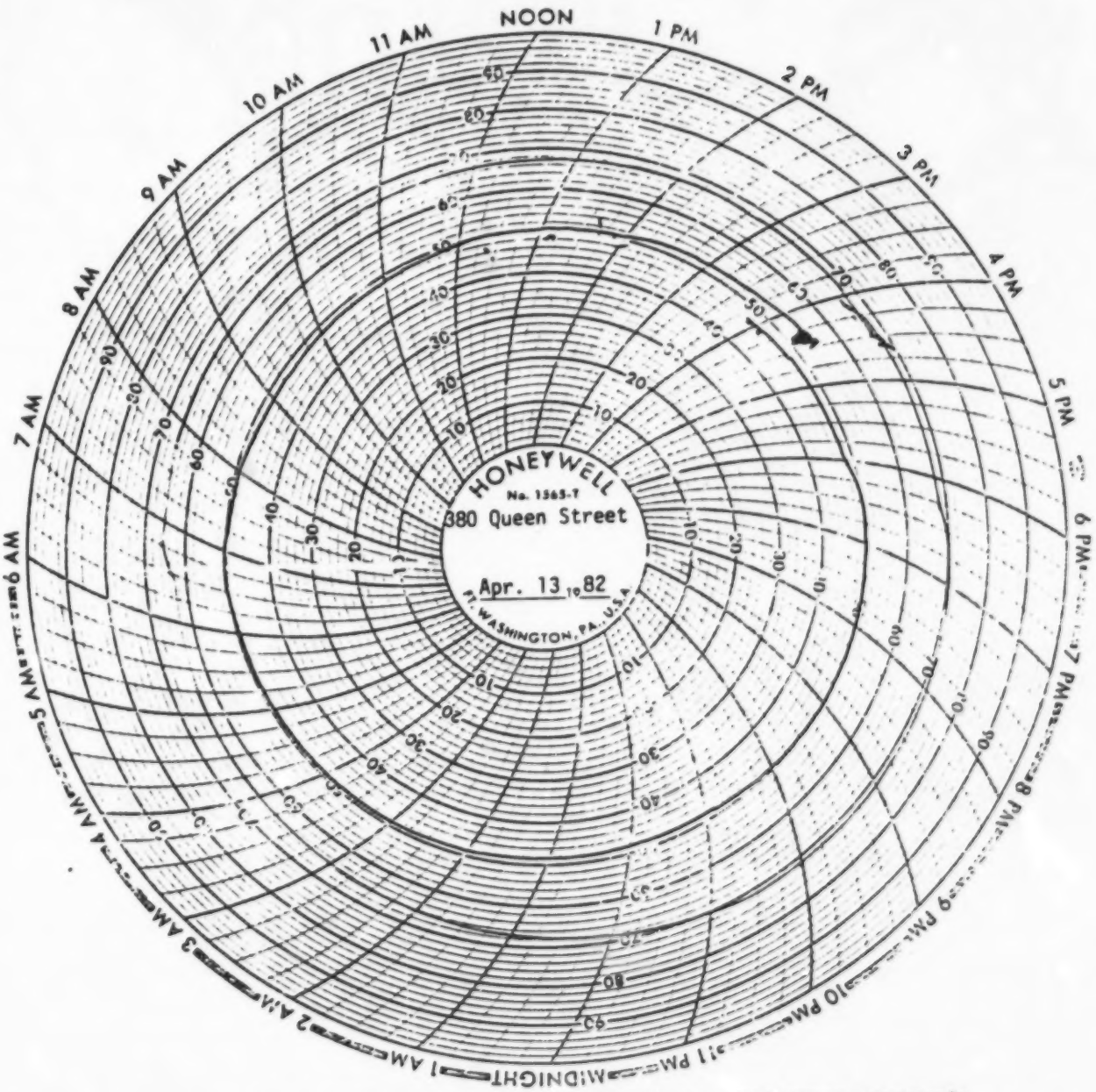
* Based on unofficial hourly temperatures for Winnipeg International Airport.
** Based on unofficial hourly windspeeds for Winnipeg International Airport: to be used for comparison only because actual windspeeds near the building are significantly lower.
*** Interior air-temperature drop over one hour divided by average interior/exterior air-temperature difference over the same hour.

FIGURE F.2 DECAY HEAT LOSS TEST - BEFORE RETROFIT



Note: Light trace represents indoor air temperature; dark trace represents indoor relative humidity (not calibrated: use as indicator of trends only.

FIGURE F.3 DECAY HEAT LOSS TEST - AFTER RETROFIT



Note: Light trace represents indoor air temperature; dark trace represents indoor relative humidity (not calibrated: use as indicator of trends only.

F.4 Energy-Use Records

Table B.8 Monthly Natural Gas Consumption

Utility: Greater Winnipeg Gas Company
Residence: 380 Queen Street

Period	Consumption (m^3)*			
	1980	1981	1982	1983
January	875	1045	731	
February	844	838	1130	
March	934	595	439	
April	660	425		
May	207	484		
June	105	224		
July	142	71		
August	76	102		
September	88	88		
October	269	130		
November	490	249		
December	810	541		
Total	5499	4791	2299	
Cost	$589.77	$615.28	$321.54	

* Conversion from gas company data recorded to nearest one hundred cubic feet. Columns may not add up due to rounding.

Table F.9 Monthly Electricity Consumption

Utility: Manitoba Hydro
Residence: 380 Queen Street

Period	Consumption (kWh)			
	1980*	1981	1982	1983
January				
February	3110(63)**	1830(58)		
March				
April	2020(62)	1400(62)		
May				
June	480(51)	840(55)		
July				
August	600(65)	840(58)		
September				
October	840(60)	1250(67)		
November				
December	1250(63)	1400(59)		
Total	8300(364)	7560(359)	2650(63)	

* January to June 1980; previous occupants.
** Number of days between readings.

F.5 Thermography

The following photographs are selected from the results of thermographic scans of the interior of the building envelope and are representative of the major problems in the house.

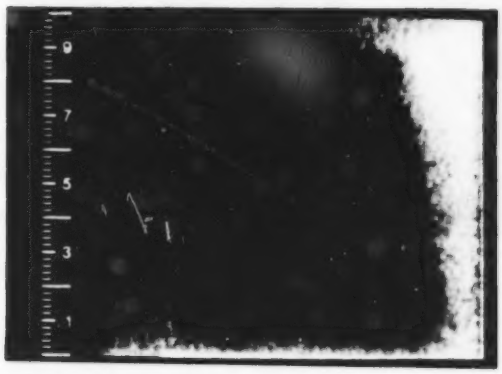


FIGURE F.4 Cold Stud Cavity in Main-Floor Exterior Wall Adjacent to Second-Floor Water-Service Piping.

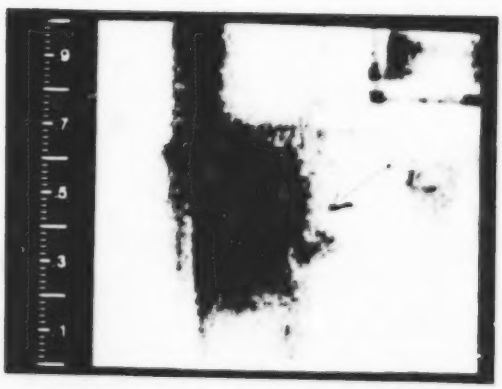


FIGURE F.5 Cold-Air Infiltration to Dormer Walls before Re-insulation.

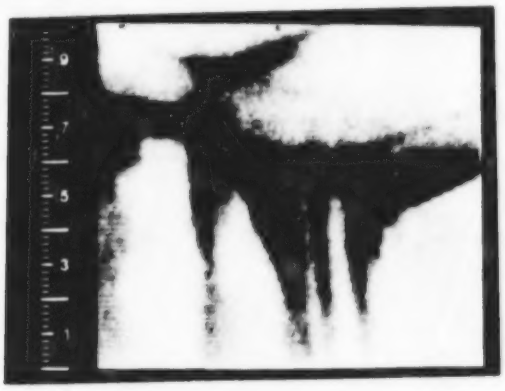


FIGURE F.6 Poor Construction and Inadequate Insulation in Walls and Ceiling of Rear Extension to House.

POOR

QUALITY

ORIGINAL